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Impact of Network Performance on Warfighter Effectiveness Using MANA

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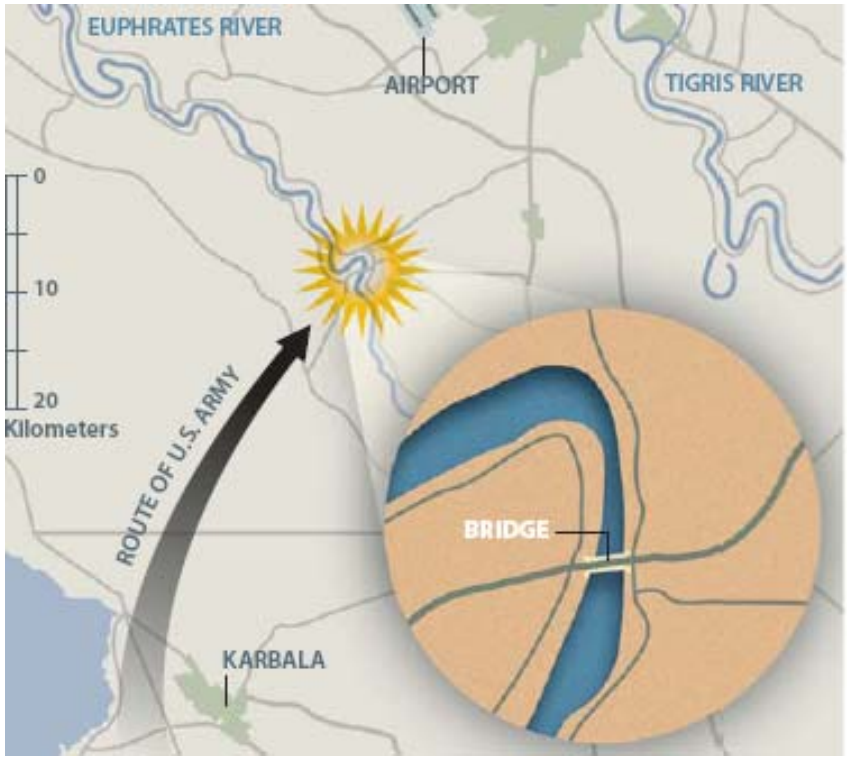
"We got nothing until they slammed into us"

-LTC Rock Marcone, BN Commander, 69th Armor, 3ID



He was told: **a single Iraqi brigade is approaching**

Reality: **he faced THREE**

Ref: Technology Review, November 2004 Issue

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Bottom Line Upfront

- **Networking "capability" will remain a scarce resource that will be rationed now & in future**

- **Communication capability needs to be modeled dynamically in all force-on-Force Simulators**
  - **It is a "Game" – network capability results from interdependencies of actions of individual agents**
  - **Metamodeling of network performance, with tools like Qualnet**
  - **Impact of wrong assumptions on key networking parameters can be significant**

Bottom Line Upfront (cont.)

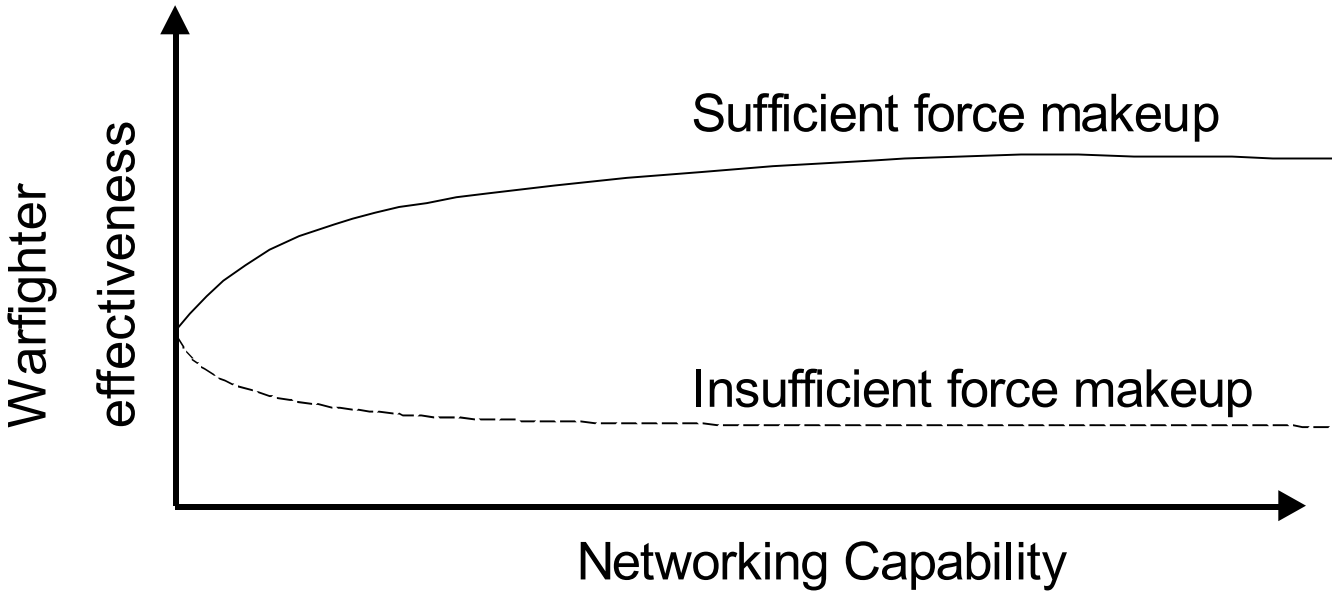


Figure: Situations Where Networking Capability Is An Effectiveness Multiplier

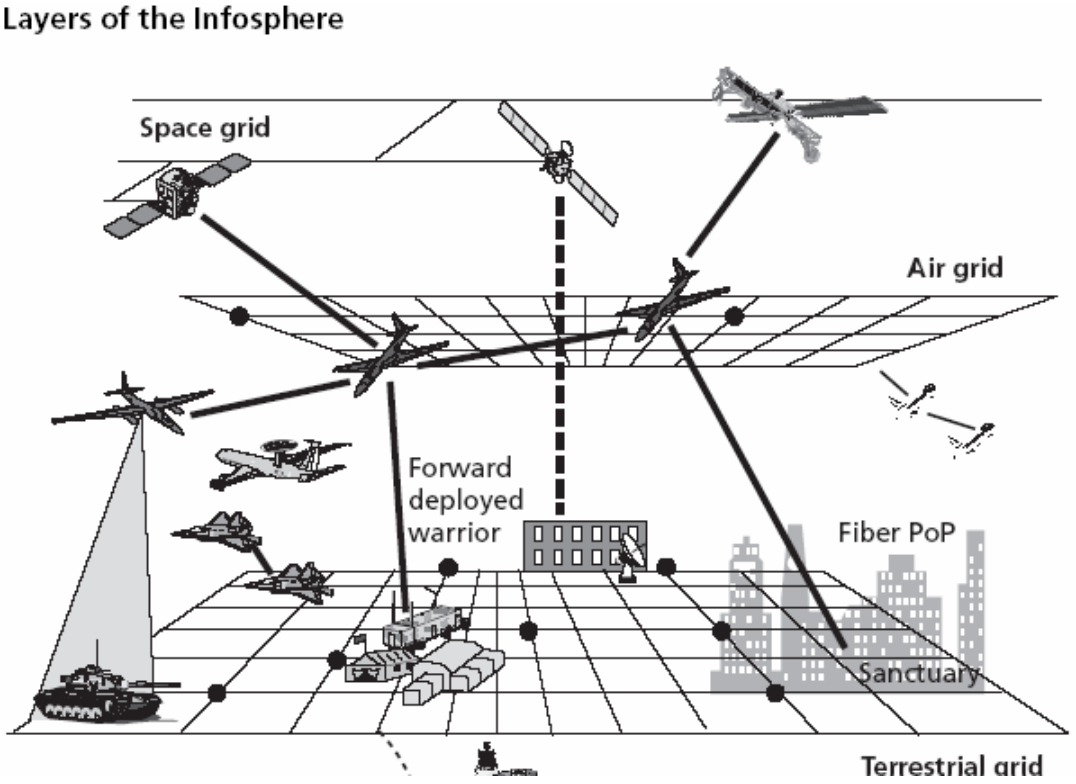
Results: Force Makeup Matters

Outline

- **Background and motivation:**
  - **What is Network Centric Operations (NCO)?**
- **Scarcity of networking capacity**
- **How Can MANA be used to assess NCO**
- **Model of impact of network performance on warfighter**
- **On-going and future work**
- **Discussion: fallacies of NCO**

What is Network Centric Operations?

The emerging concept of networked operations, referred to by DOD as network-centric operations [NCO] involves developing communications and other linkages among all elements of the force to create a shared awareness of operations.



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*Background – Lessons Learned Report**

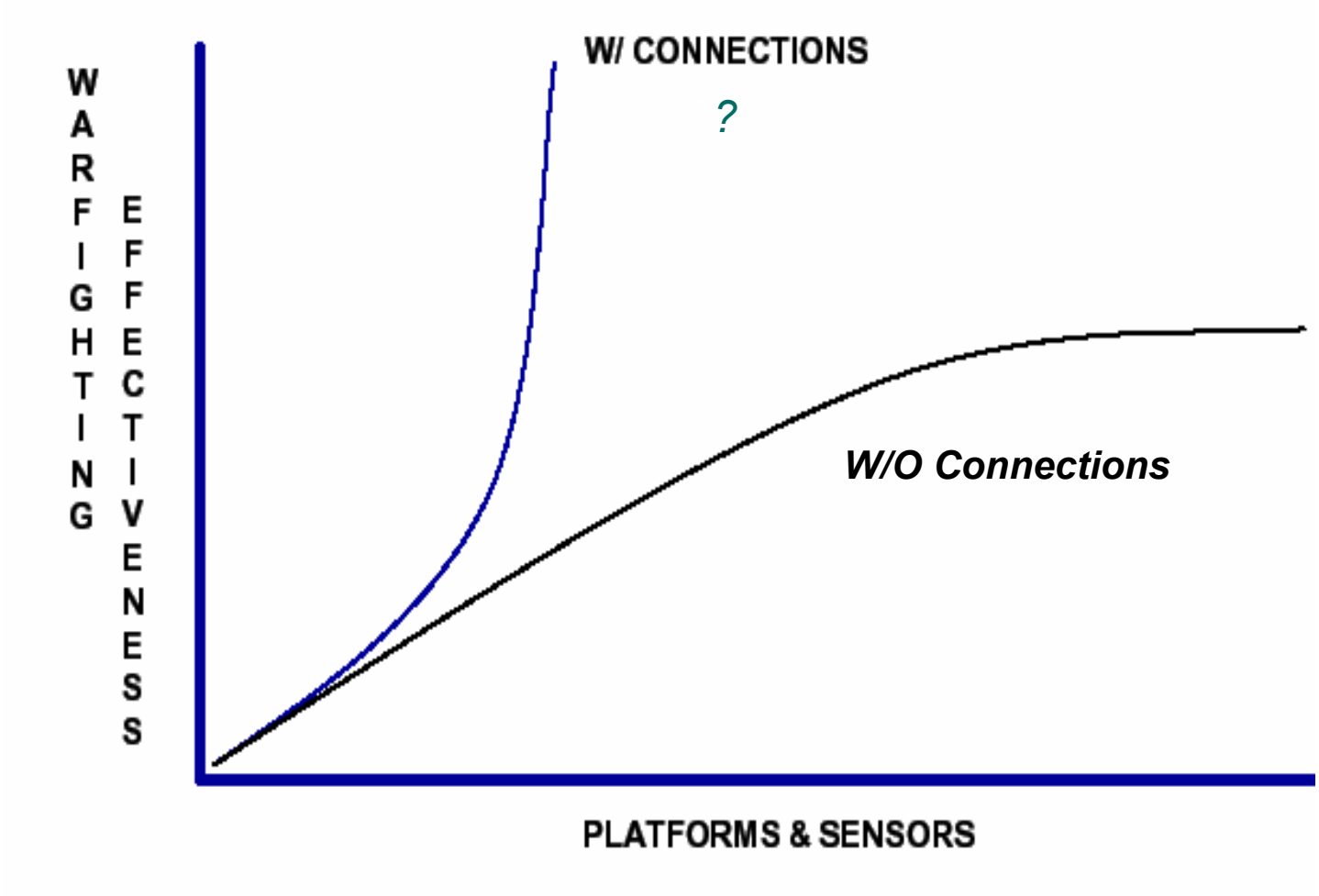
- **Pros of NCO (as seen through current operations)**
  - **Improvements in force networks & use of precision weapons are primary reasons for the overwhelming combat power in OIF**
- **Cons of NCO:**
  - **Large increases in the pace of operations & Volume of information have overwhelmed commanders at times**

  - Slow or inaccurate [BDA] assessments can negate improvements in the speed of operations, battle damage assessments didn't keep up with the pace of operations

  - **The improved ability to share view of the battlefield and communicate quickly has compressed the time required for analysis and decision making**

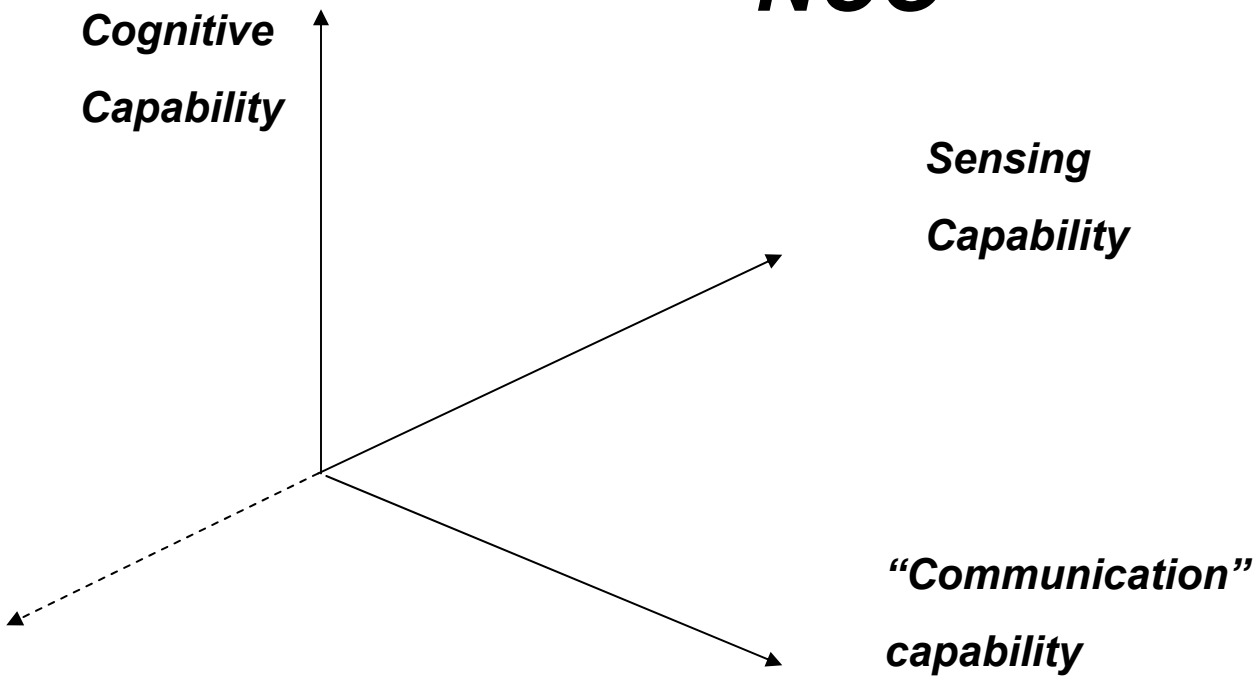
GAO-04-547: "Recent Campaigns Benefited from Improved Communications and Technology, but Barriers to Continued Progress Remain" ,

Motivating Research Question:



What is the Marginal Increase in Warfighter Effectiveness From Networking.

Tools: MANA Captures At Least Three Components of Warfighter Performance of NCO

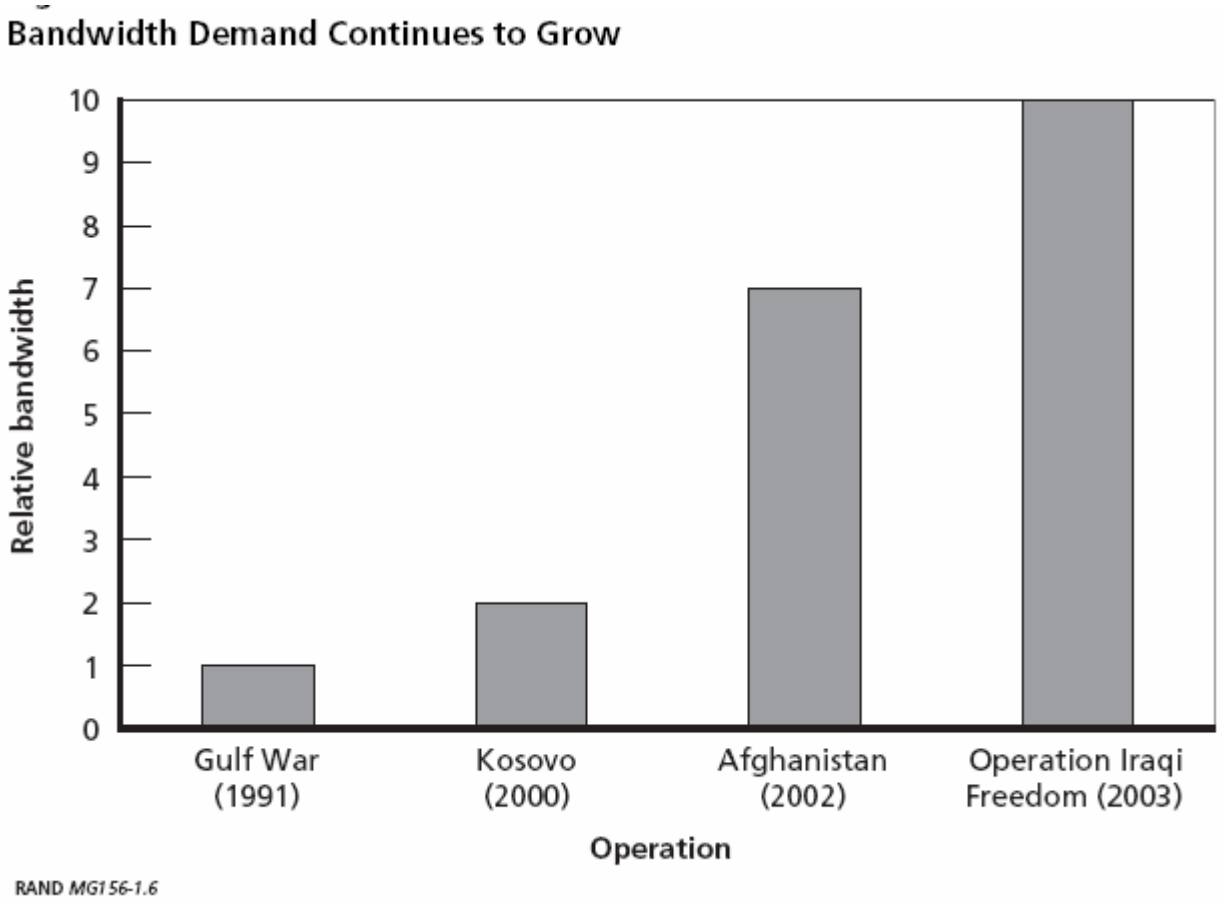


Performance Components:

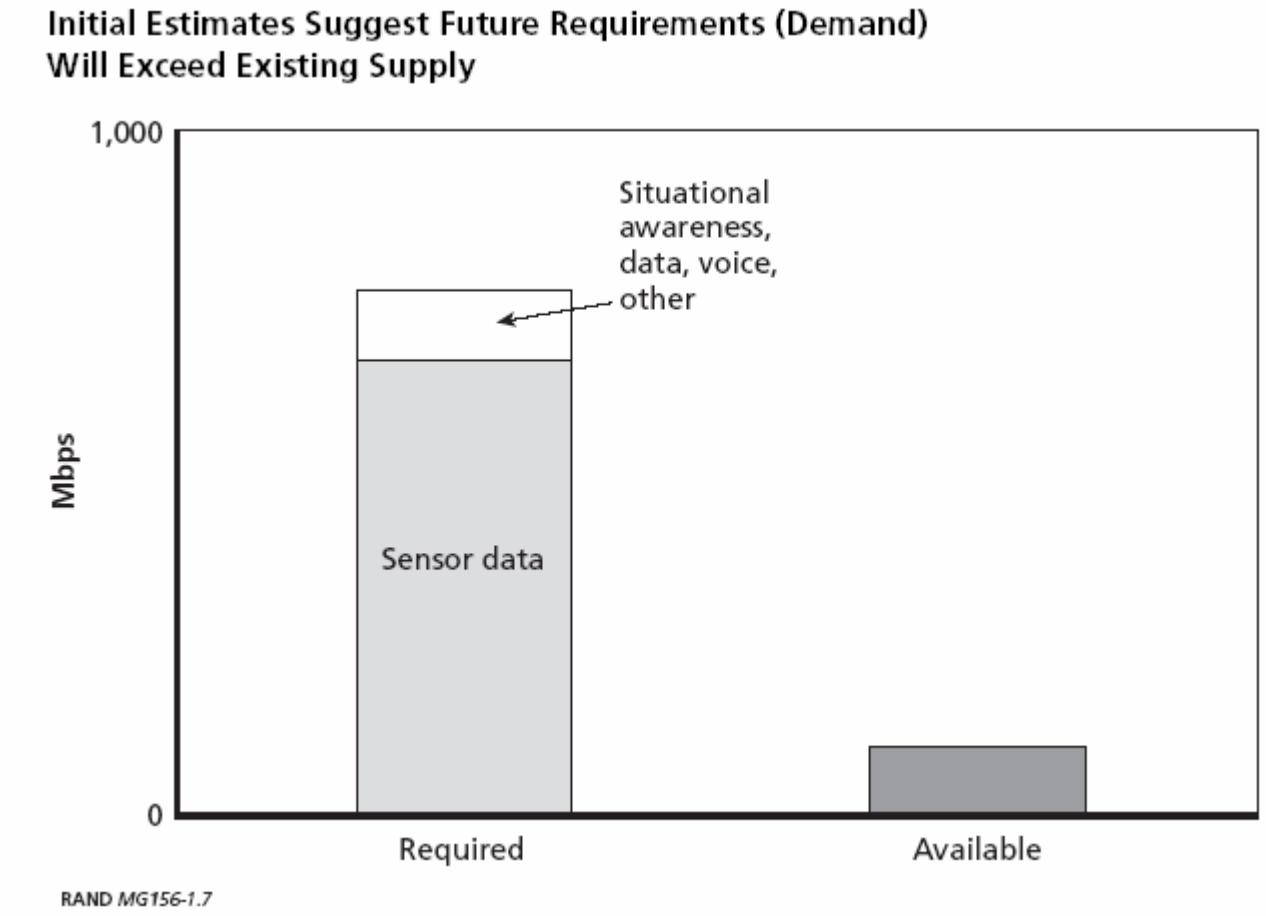
- **Sense/acquire data (sensors)**
- **Disseminate and communicate data (networks)**
- **Interpret, fuse, react to the data (cognition)**

Networking Capability Is A Dynamically Changing, Scarce Resource

Demand for Networking Capability Will Continue To Outpace Supply

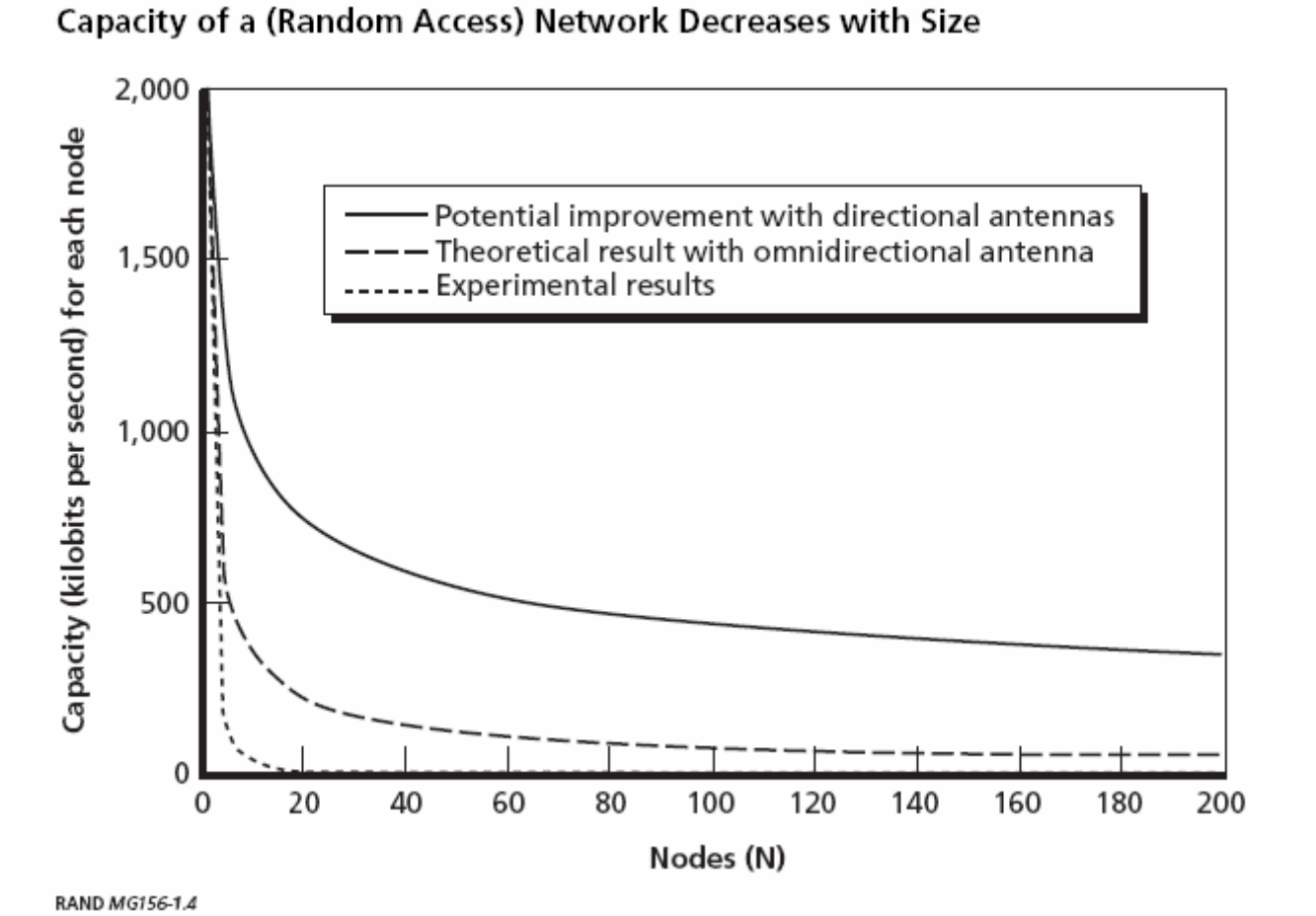


Type of Data Message Matters: Future Force Requirements Exceed Current Availability

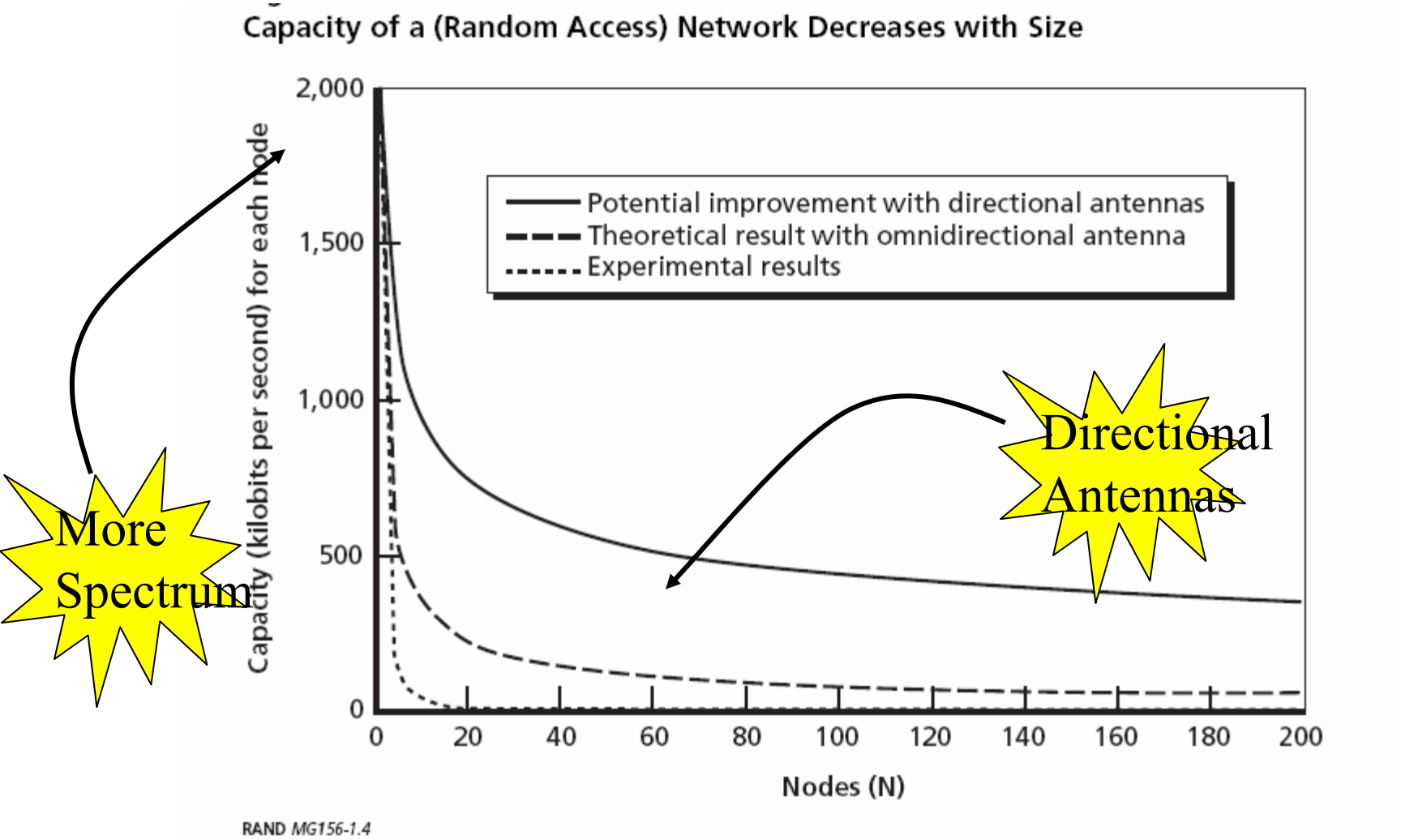


Can't "train as we fight"

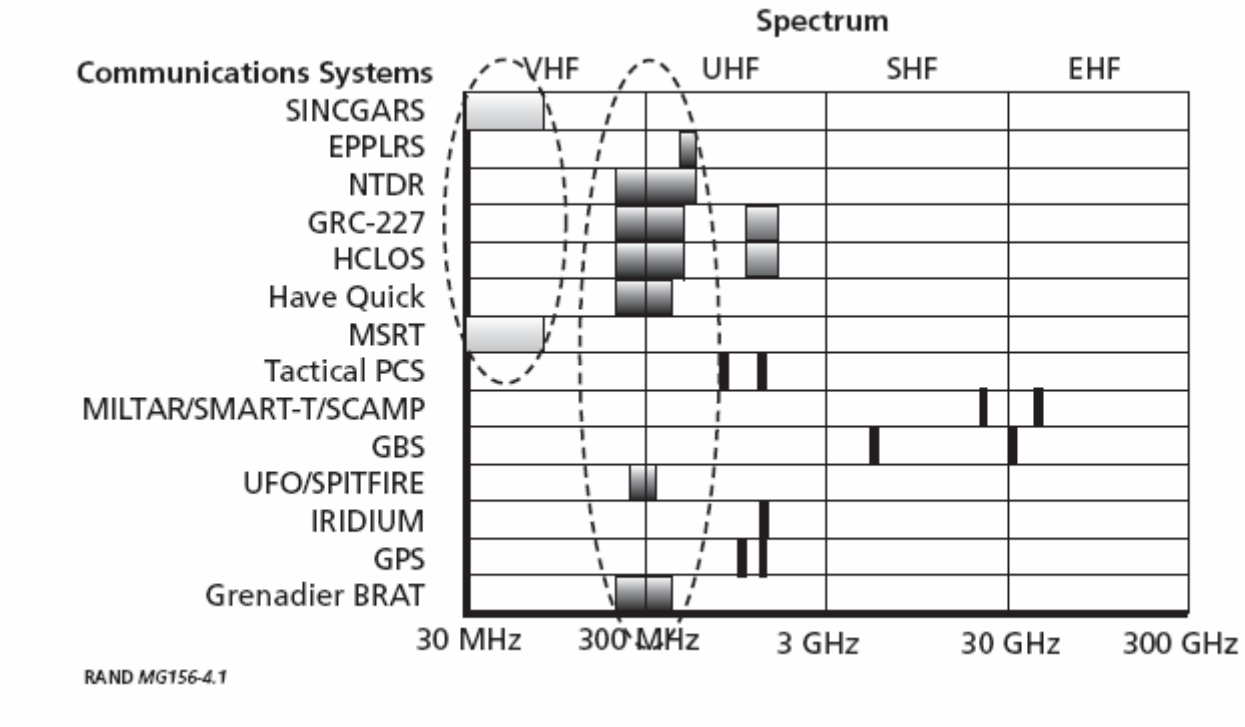
Wireless Capacity Doesn't Scale: The More Users, The Less Capacity Per User



Directional Antennas and Spectrum Improve Scalability of Wireless networks



Capacity Comes From Spectrum, "Good Spectrum" is Scarce



Bottom-Line: Avoid Assuming Unlimited "Messaging"… Especially in Urban Ops

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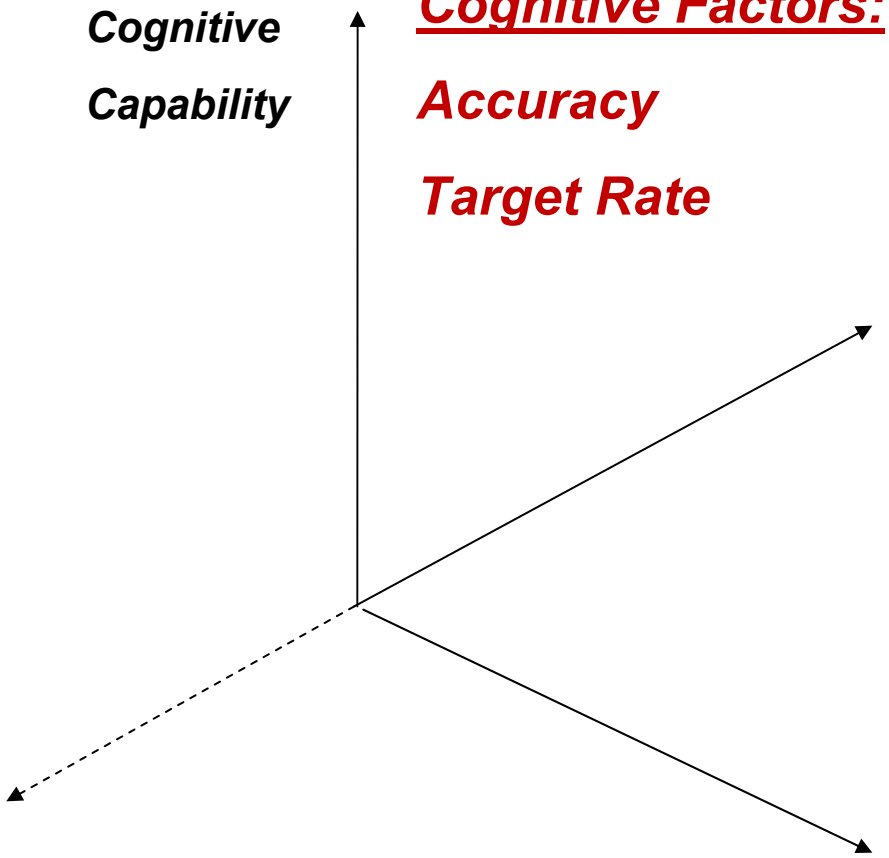
How Can MANA Be Used to Assess Network Centric Operations

(Or at least account for scarcity of networking capability)

MANA Captures At Least Three Components of Warfighter Effectiveness of NCO



Cognitive Factors:

- Accuracy
- Target Rate

Sensing Factors:

- Sensing

Comm Factors:

- Capacity
- Latency
- Reliability

A MANA Scenario Was Examined

- *Blue Forces (7)*
  - *Two squads*
    - *Indirect Sqd (1)*
    - *Infry Sqd (6)*

Red Forces (100)

Red Tendency

Blue Goal

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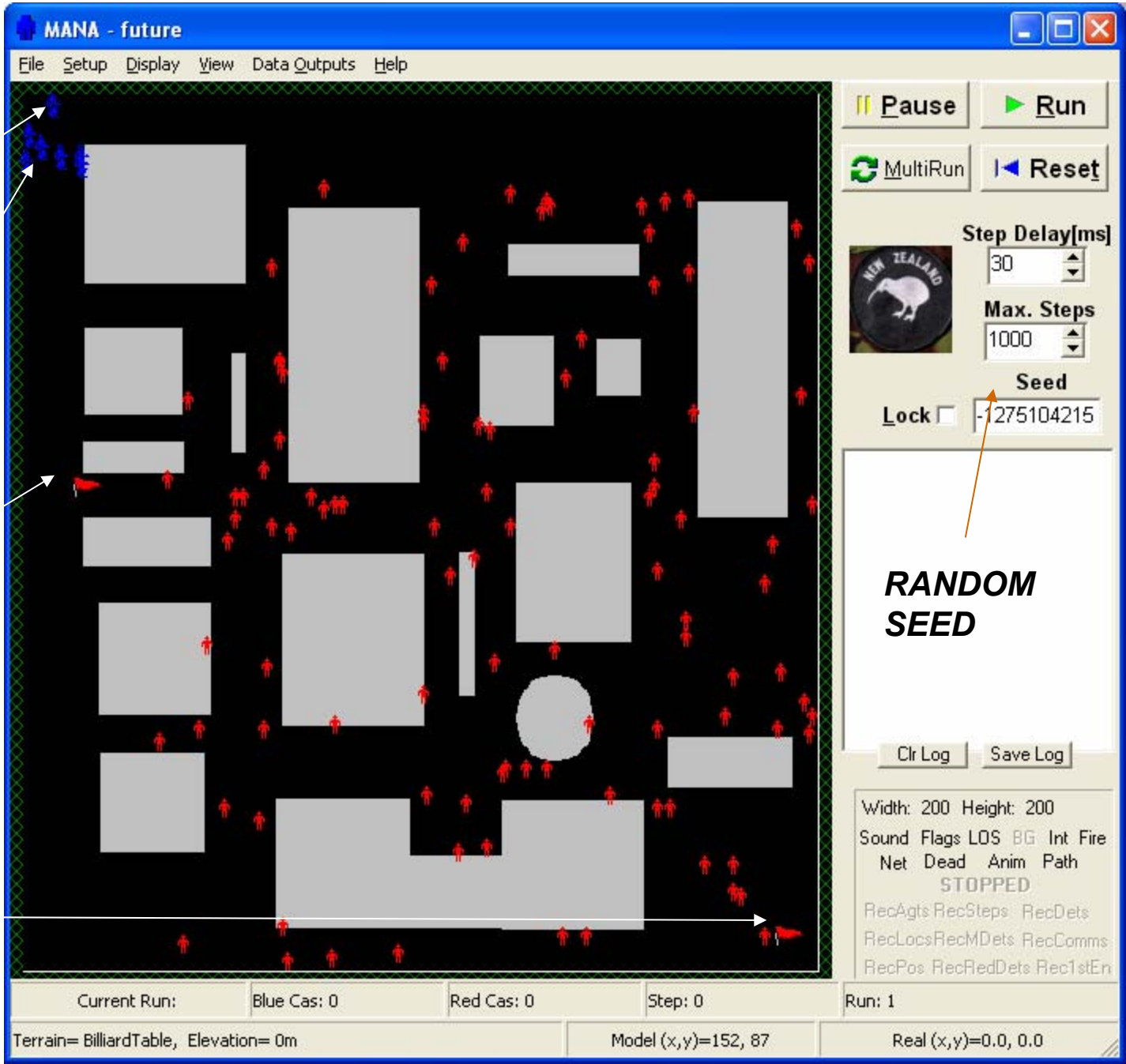
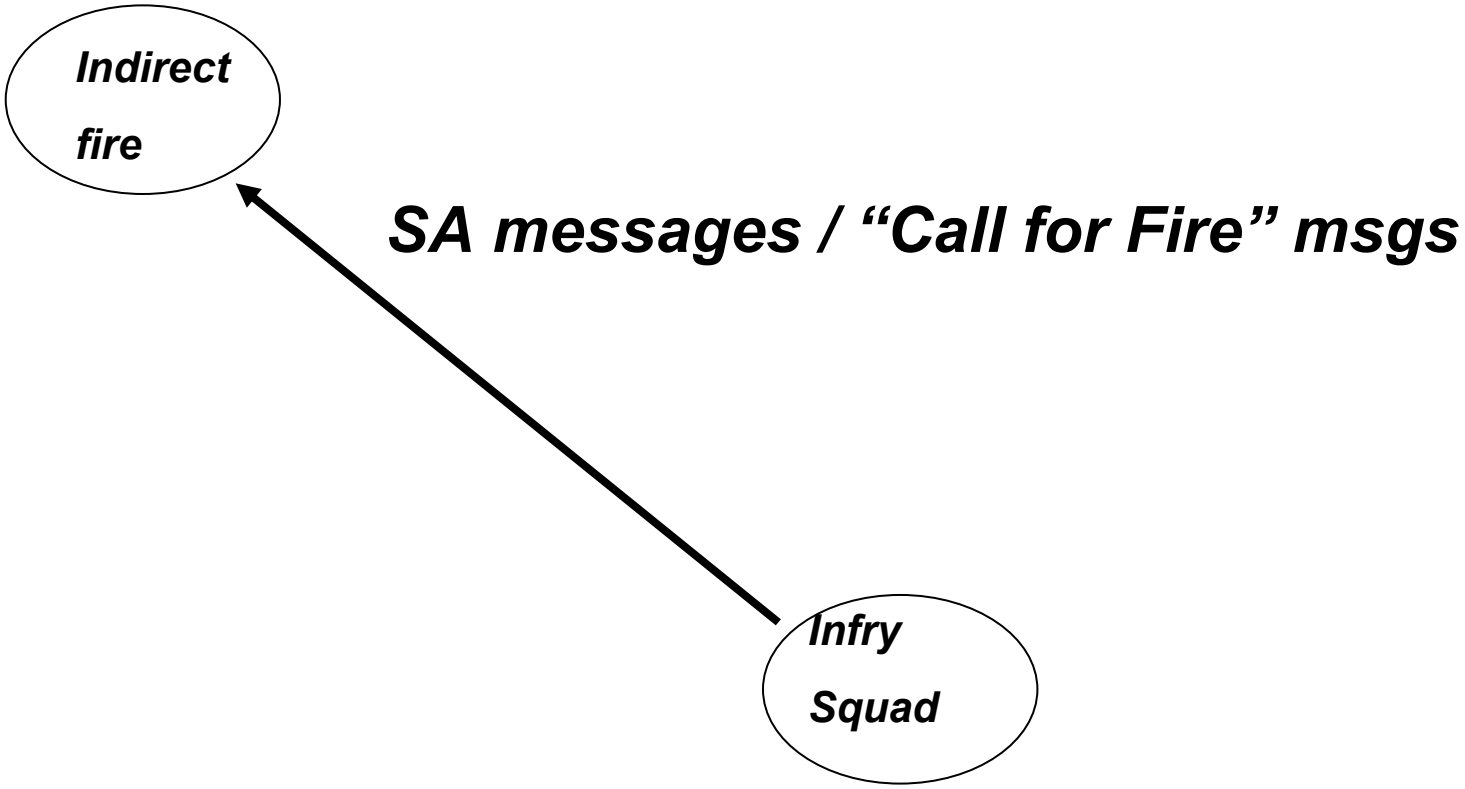


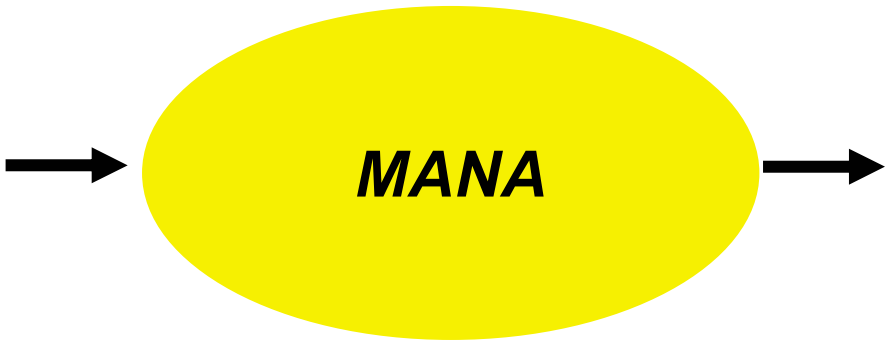
Basic Scenario: One Link Between Infry Squad (Sensors) and "Indirect Fire Unit"



Thousands of MANA Experiments Result in Translation of Factors into Effectiveness

Factors:

- ***Capacity***
- ***Reliability***
- ***Latency***
- ***Accuracy***
- ***Situation Handling (Target Rate)***
- ***Sensing***



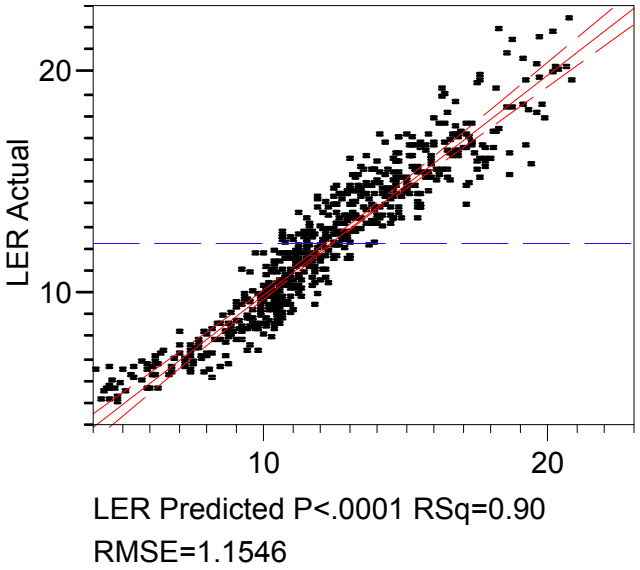
Output:

- ***Warfighter Effectiveness***

LER Goal?

"DATA FARMING EXERCISE"

Statistical Analysis of Results Produced a Model



LER= -72.62-0.4839*Capacity-2.0485*Latency-0.00667*(Capacity-56.3158)*(Latency-0.94737) + 0.0369*Accuracy-0.00412(Latency-0.94737)*(Accuracy-75)+0.000699*TargetRate-0.00513*(Latency0.94737)*(TargetRate-125) + 0.0672*Sensing0.000842*(Capacity56.3158)*(Sensing-62.5)-0.0241*(Latency-0.94737)*(Sensing-62.5)+0.000358*(Accuracy-75)*(Sensing-62.5)+0.000104*(TargetRate-125)*(Sensing-62.5) +26.802*Ln(Capacity) +0.197*(Capacity-56.3158)*(Ln(Capacity)-3.87424)+1.55(Latency-0.94737)*(Ln(Capacity)-3.87424)-0.0189*(Accuracy-75)*(Ln(Capacity)-3.87424)+0.0751*(Sensing-62.5)*(Ln(Capacity)-3.87424)

Plot of Actual Results vs. Modeled Result is "Good"

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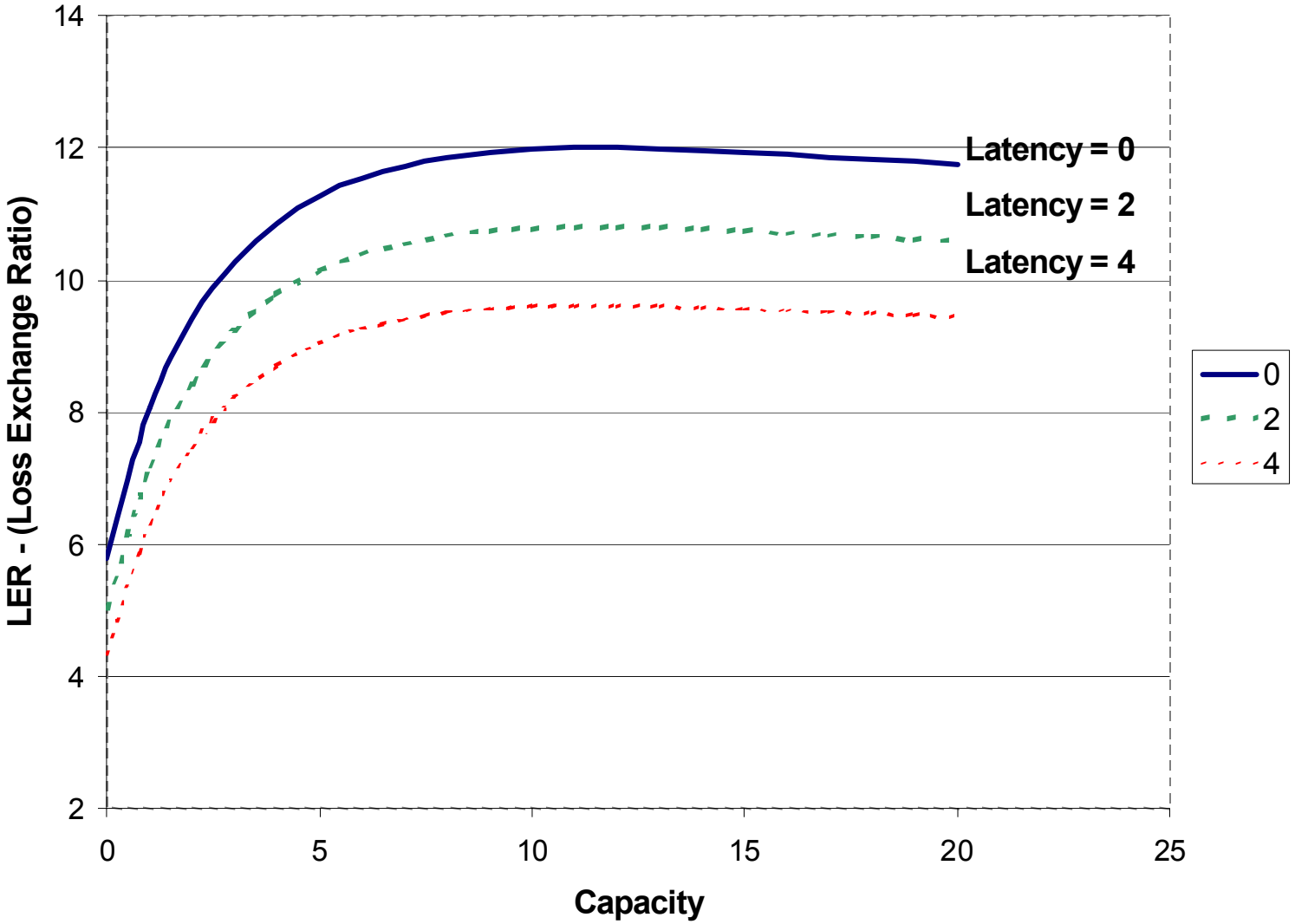
** Case: Dynamic reliability incorporated*

Result From Model: Capacity Improves Warfighter Effectiveness to a Point



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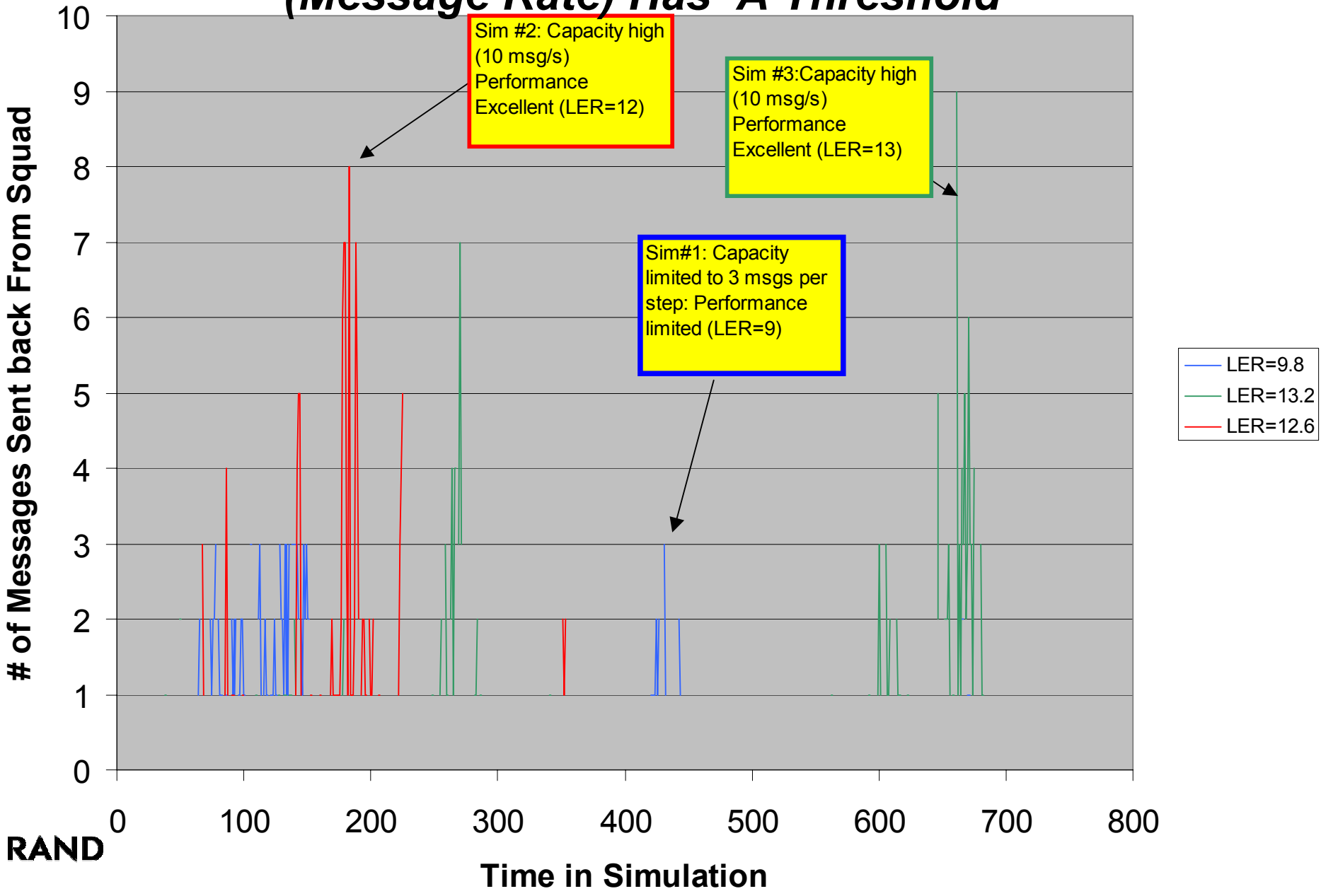
** Case: Static reliability incorporated*

Examination of Three Individual Runs: Capacity (Message Rate) Has A Threshold



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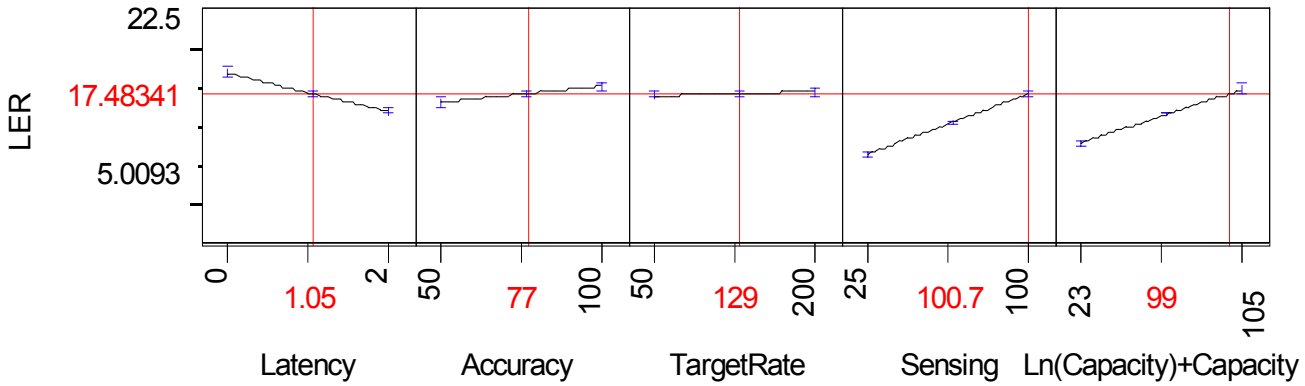
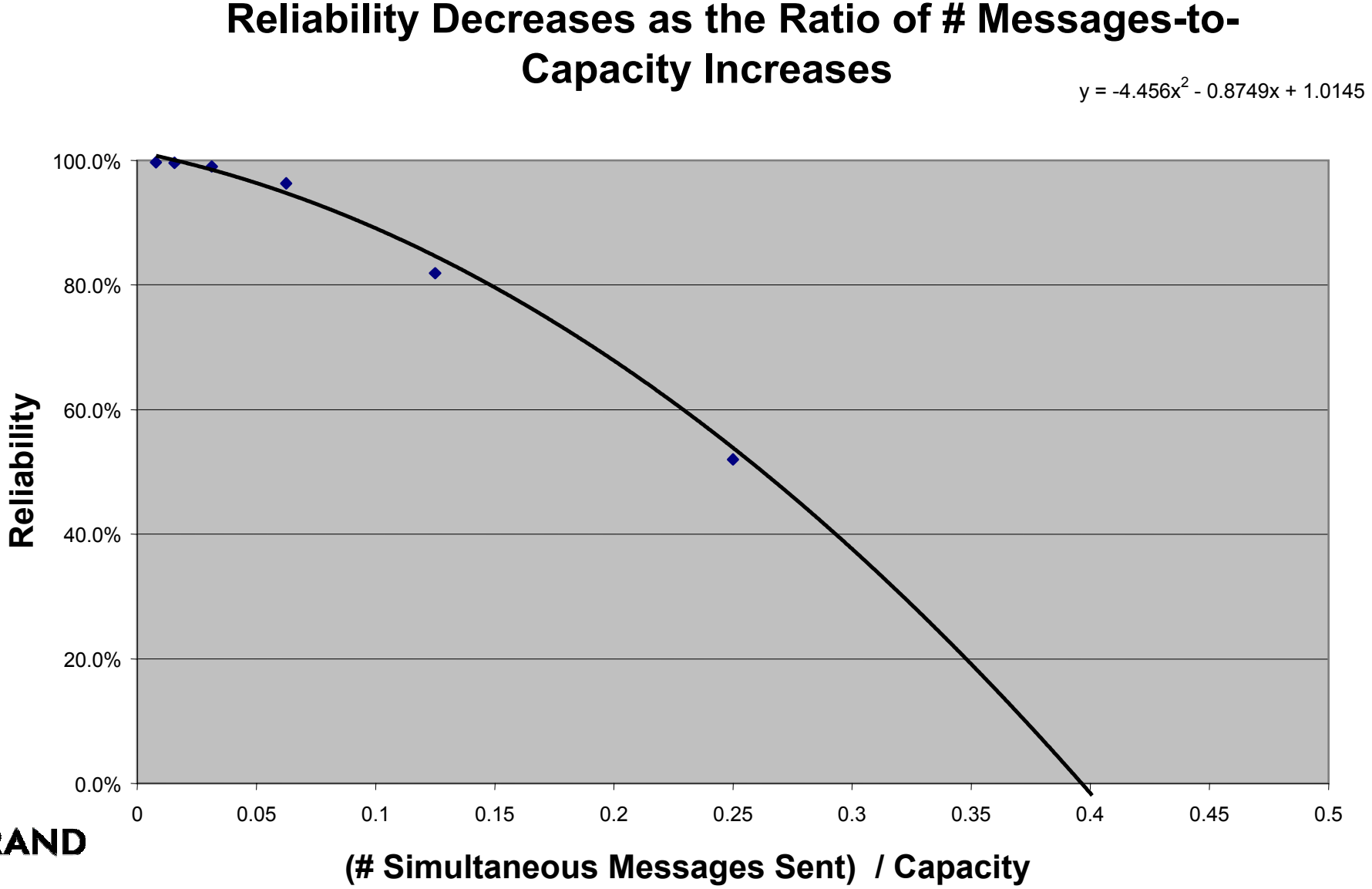
Statistical Analysis of Results Produced a Model (cont.)



Intuitive Results: Better Sensing, More Capacity, Lower Latency Improved Loss Ratio

New Experiments: MANA Was Made to Calculate Reliability Dynamically



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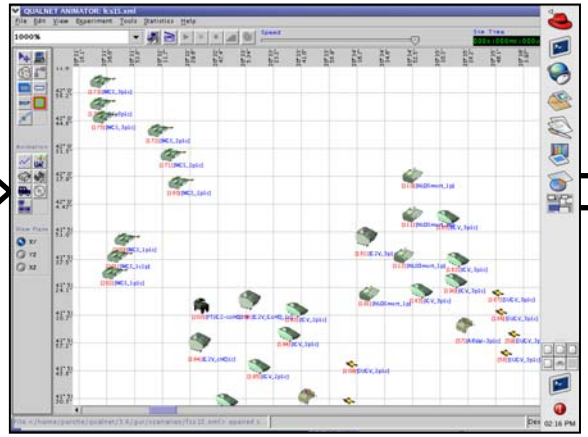
MetaModel of Communication Performance Developed Using Qualnet

Parameters (Tech. Options)

- Traffic volume & type
- Terrain type
- Number of Nodes
- Node mobility
- Other factors

Qualnet Simulations

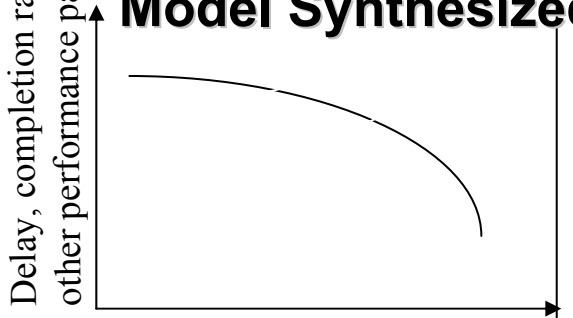


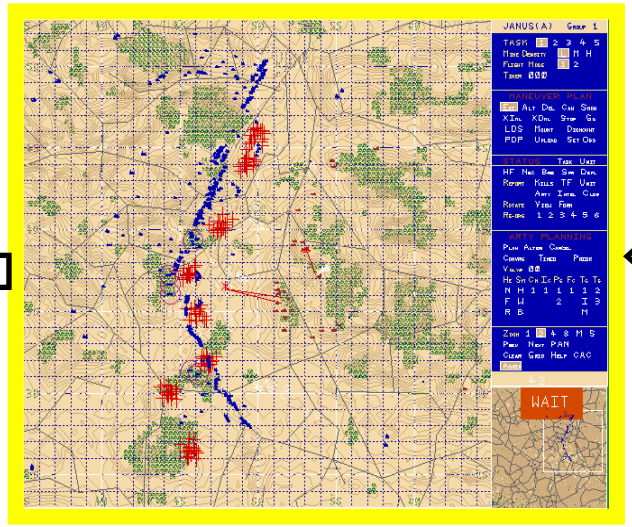
Performance Data

For each parameters (Message type, tech, etc,)

- Completion rates
- Latency

Comms/Ntwrk Model Synthesized





Force on Force Simulations

Warfighter Effectiveness

e.g., mission execution, attrition, etc.

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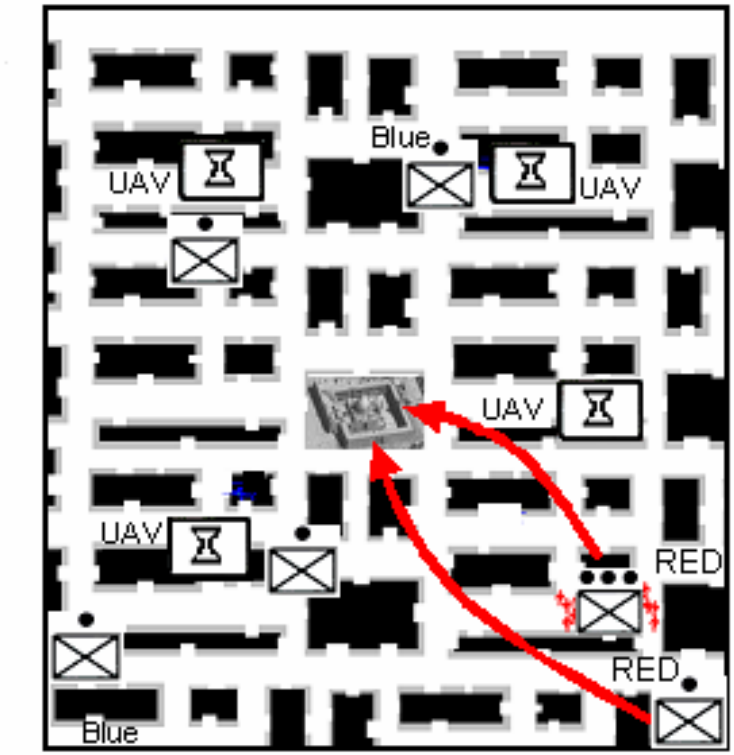
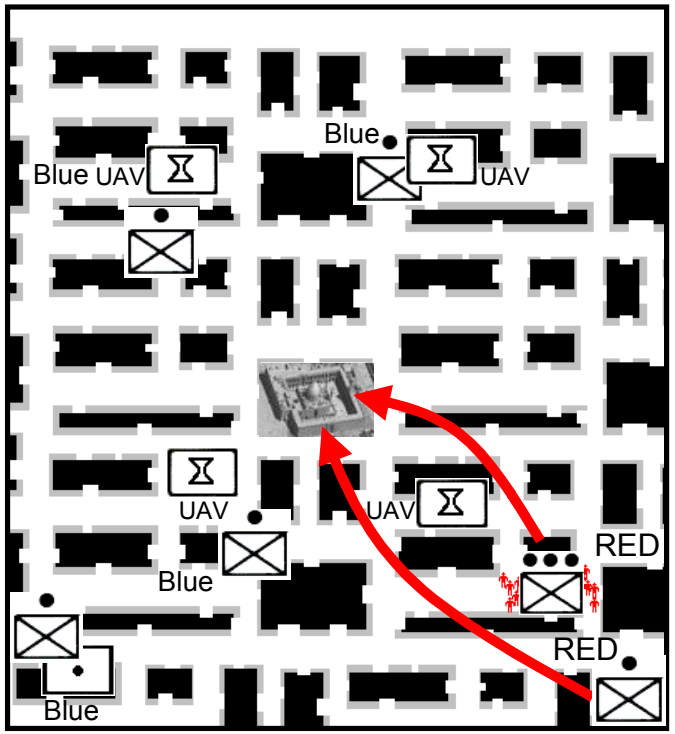
A Different Scenario Developed at PAIW Workshop

Variant 1: Direct Fire Fight

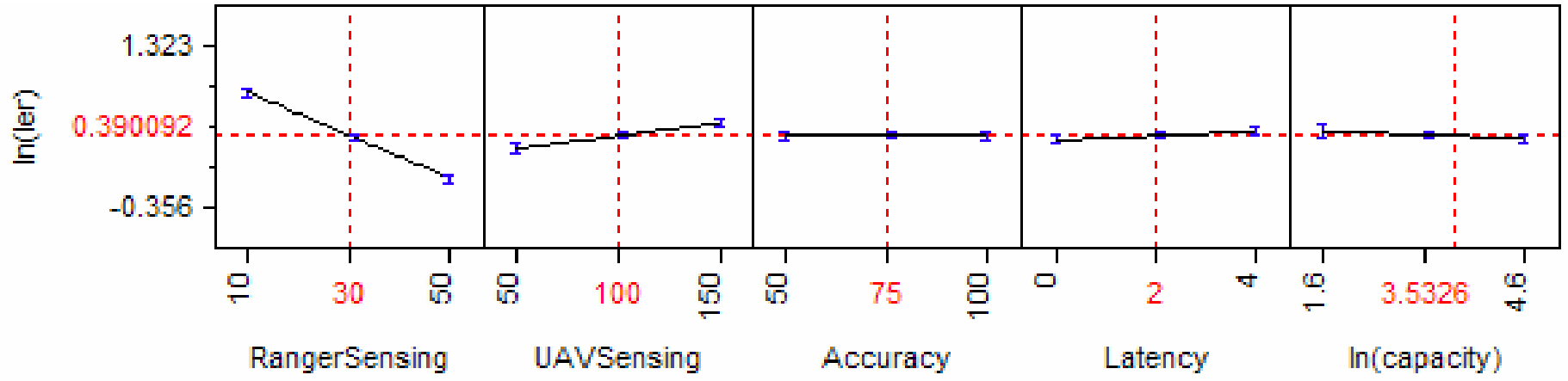


Variant 2: Indirect Fire Support



- **Blue goal: secure perimeter & keep Red out of mosque**
- **Blue uses situational awareness from UAV sensors**
- **Question: how critical is networking performance to Blue**

Result From "Data Farming" On Variant #1: Blue Outcome Not Helped By Networking By One Measure (LR)



1. ***Not all networking capability factors improved the outcome***
2. ***Increased networking capability made outcome slightly worse in terms of loss ratio (LR)***
3. ***Neither did increased manpower in terms of loss ratio***

Summary of Simulation Results From Variant 1 Based on Two Outcome Measures

"Direct Fire" Variant

	6-man	9-man	12-man
Mean LER	1.64	1.67	1.76
Max LER	3.75	3.83	4.18
Min LER	0.7	0.66	0.78
Mean Red Kills	7.2	10.39	13.4

Recap: Scenario

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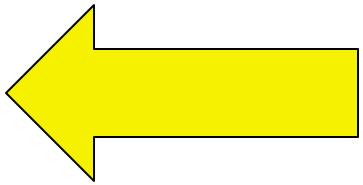
Retrospect: Did Variant #1 Really Suggest That Networking Hurt The Warfighter?

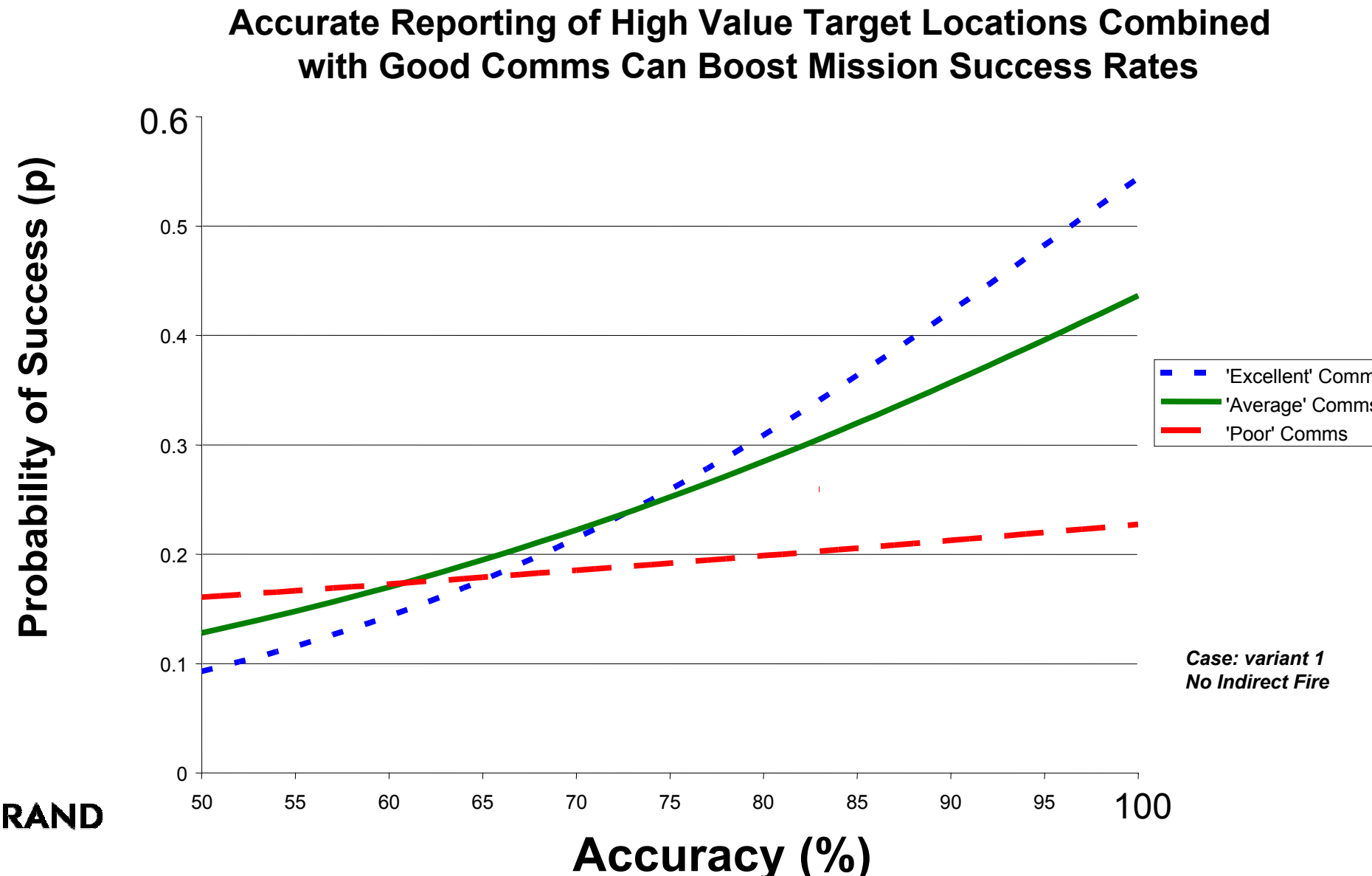
	6-man	9-man	12-man
Mean LER	1.64	1.67	1.76
Max LER	3.75	3.83	4.18
Min LER	0.7	0.66	0.78
Mean Red Kills	7.2	10.39	13.4
Likelihood Blue Objective Achieved	10%	17%	28%

Repeated Analysis With New Metric



Unclear: Perhaps we chose the wrong performance measure

Resulting Model: Reliable Communication of Accurate Information is Needed to Increase Odds of Success



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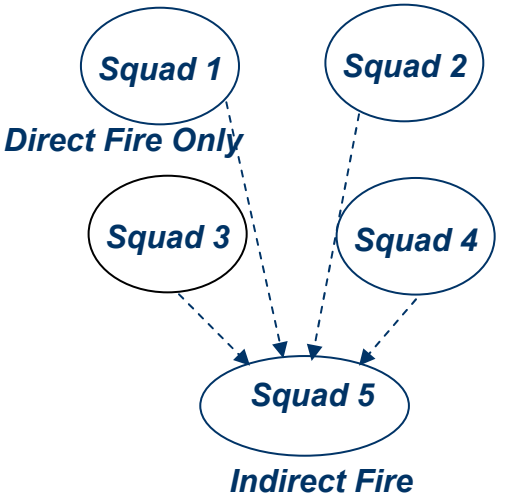
Summary of Simulation Results From Enhanced Force makeup (Variant 2)

"Indirect Fire" Variant

	6-man	9-man	12-man
Mean LER	1.92	1.19	1.19
Max LER	5.72	3.65	4.13
Min LER	0.65	0.52	0.48
Mean Red Kills	15.99	17.52	17.58
Likelihood Blue Objective Achieved	34%	39%	38%

Recap: Scenario



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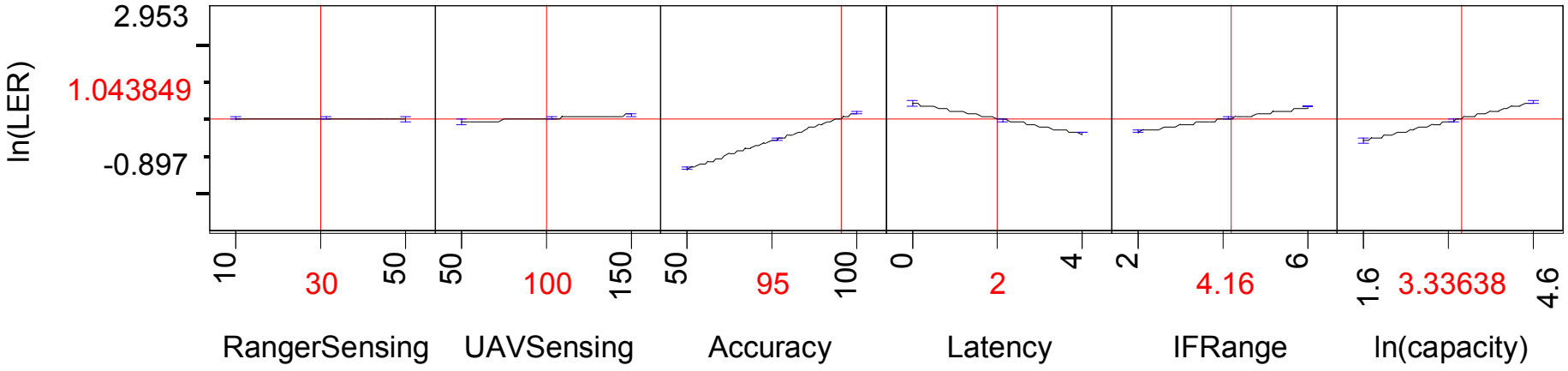
Result From "Data Farming" With Enhanced Force (Variant #2): Blue Does Well !



1. ***Networking capability factors do improve the outcome***
2. ***Increased networking capability made things better***
3. ***Good results not dependent on manpower***

Apparently Force Makeup Matters More Than Networking Performance

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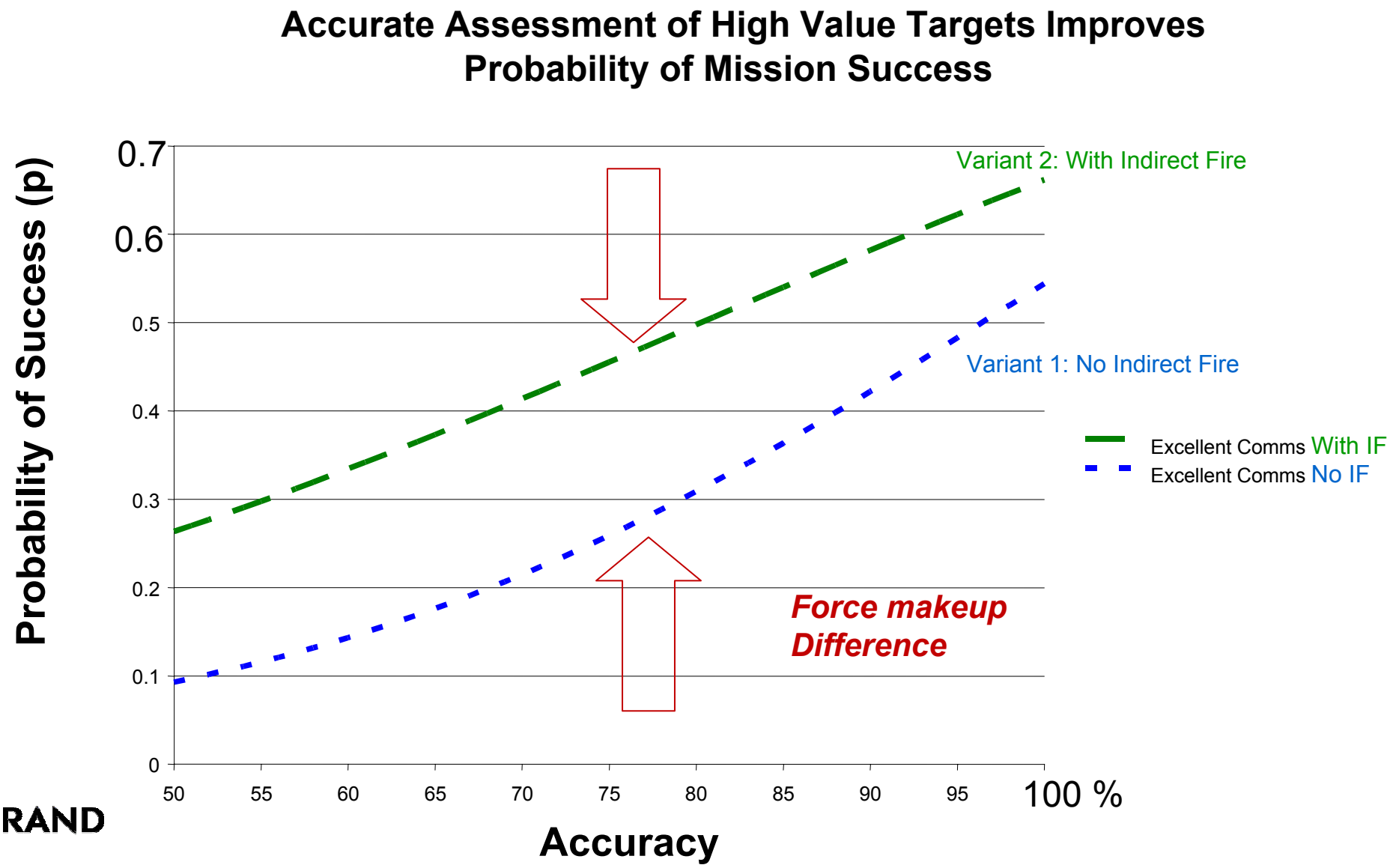
Results: Accuracy Helps, More Appropriate Force Helps Most



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Conclusions From MANA Analysis of Several Different Scenarios

- **Force makeup matters: the impact of information on warfighter can be large but very much scenario/force-structure dependent – and more isn't always better**

- **Communication/networking capability needs to be modeled *Dynamically* in All Force-on-Force Simulators**
  - **It is a "Game" – network capability results from interdependencies of actions of individual agents**
  - **Metamodeling of network performance is possible with Tools like Qualnet**
  - **Impact of wrong assumptions on communications capability could be significant**

- **Analysis methods: the costs of networking and communication capability must always be incorporated (not just benefits)**

Bottom-Line: Force Structure Matters

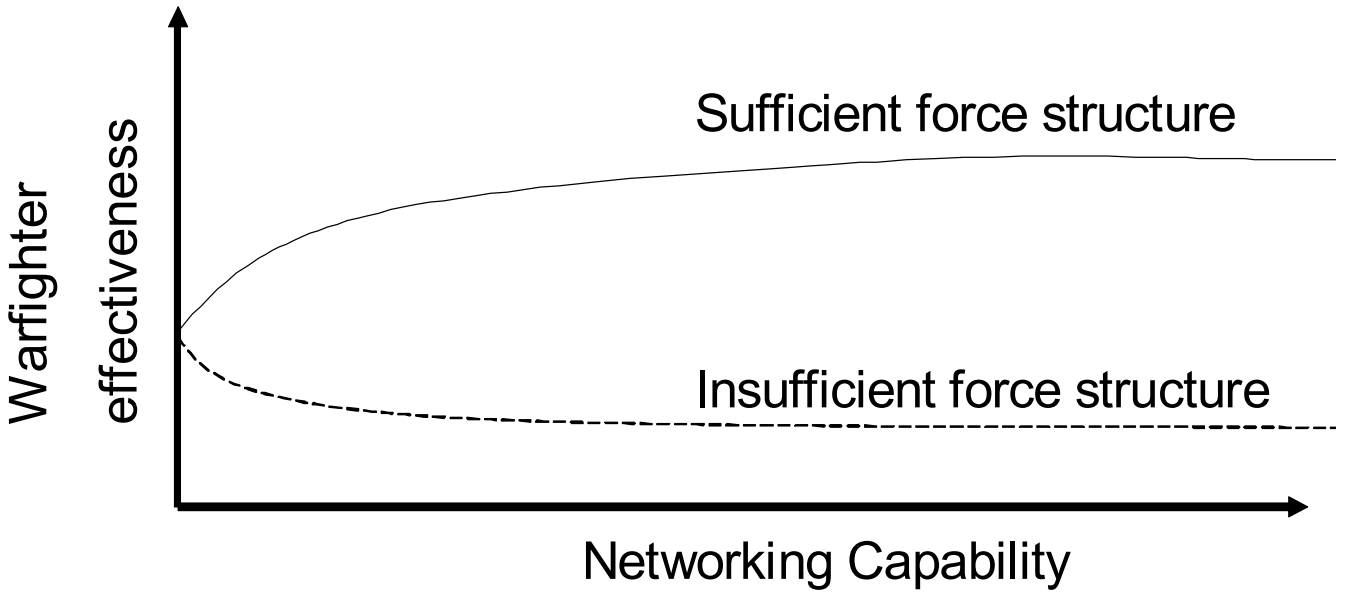
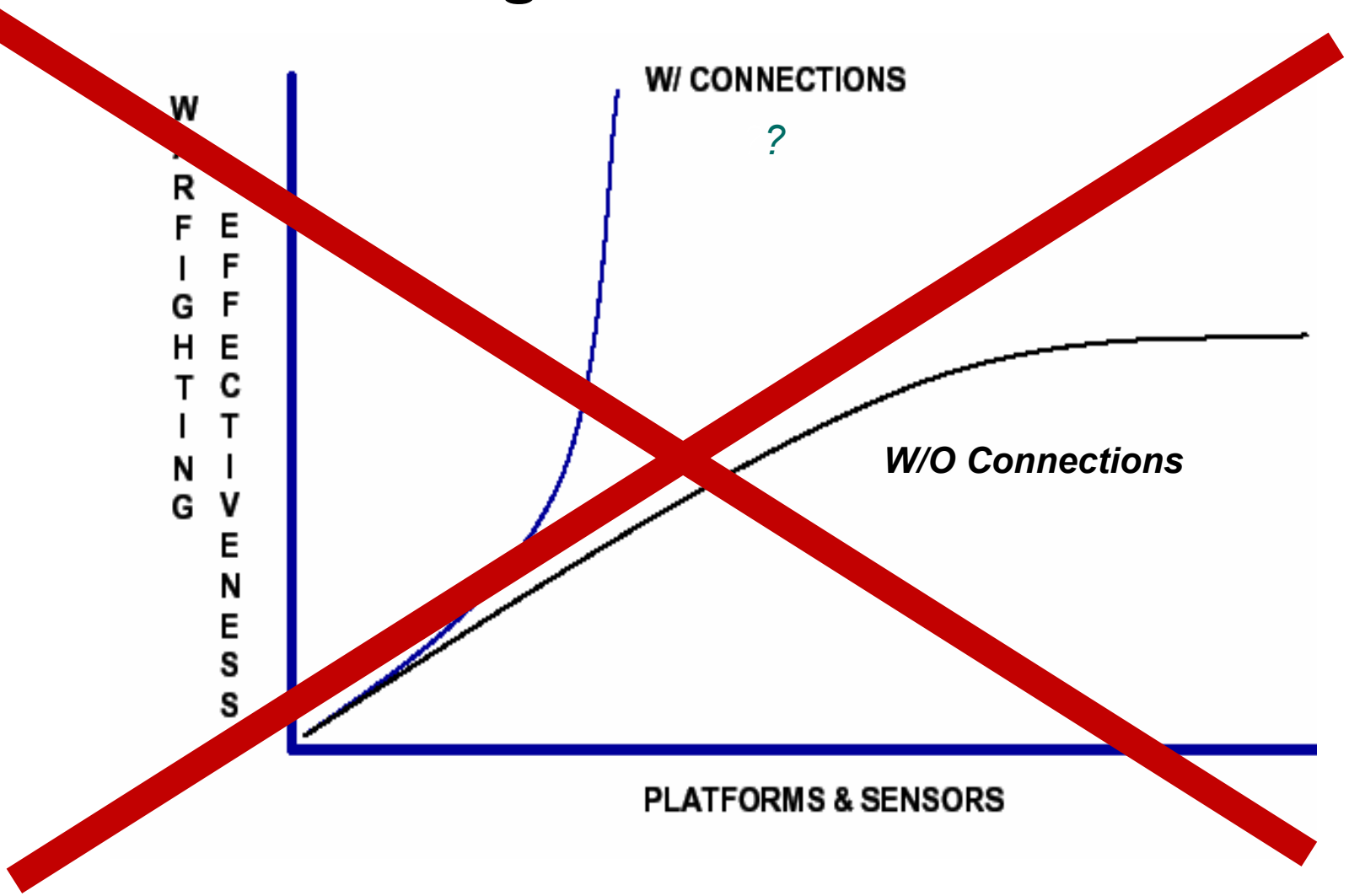


Figure 22: Situations Where Networking Capability Is An Effectiveness Multiplier

Motivating Research Question:



What is the Marginal Increase in Warfighter Effectiveness From Networking.

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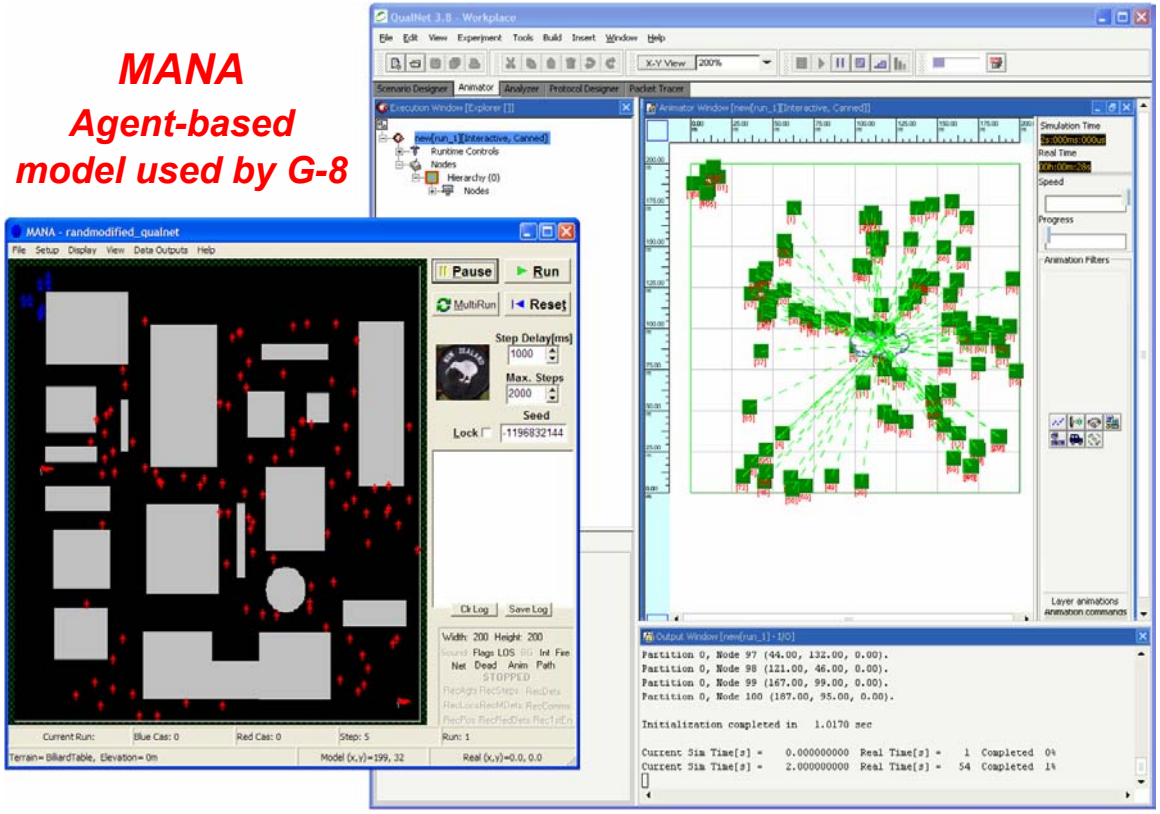
Next : Direct Integration of Network Simulator and Force-on-Force Simulator

MANA
Agent-based model used by G-8



Qualnet

Scalable; designed to run on parallel machines

Node status (alive?)

Msg status (received?)

Force-on- force Model

Network Model

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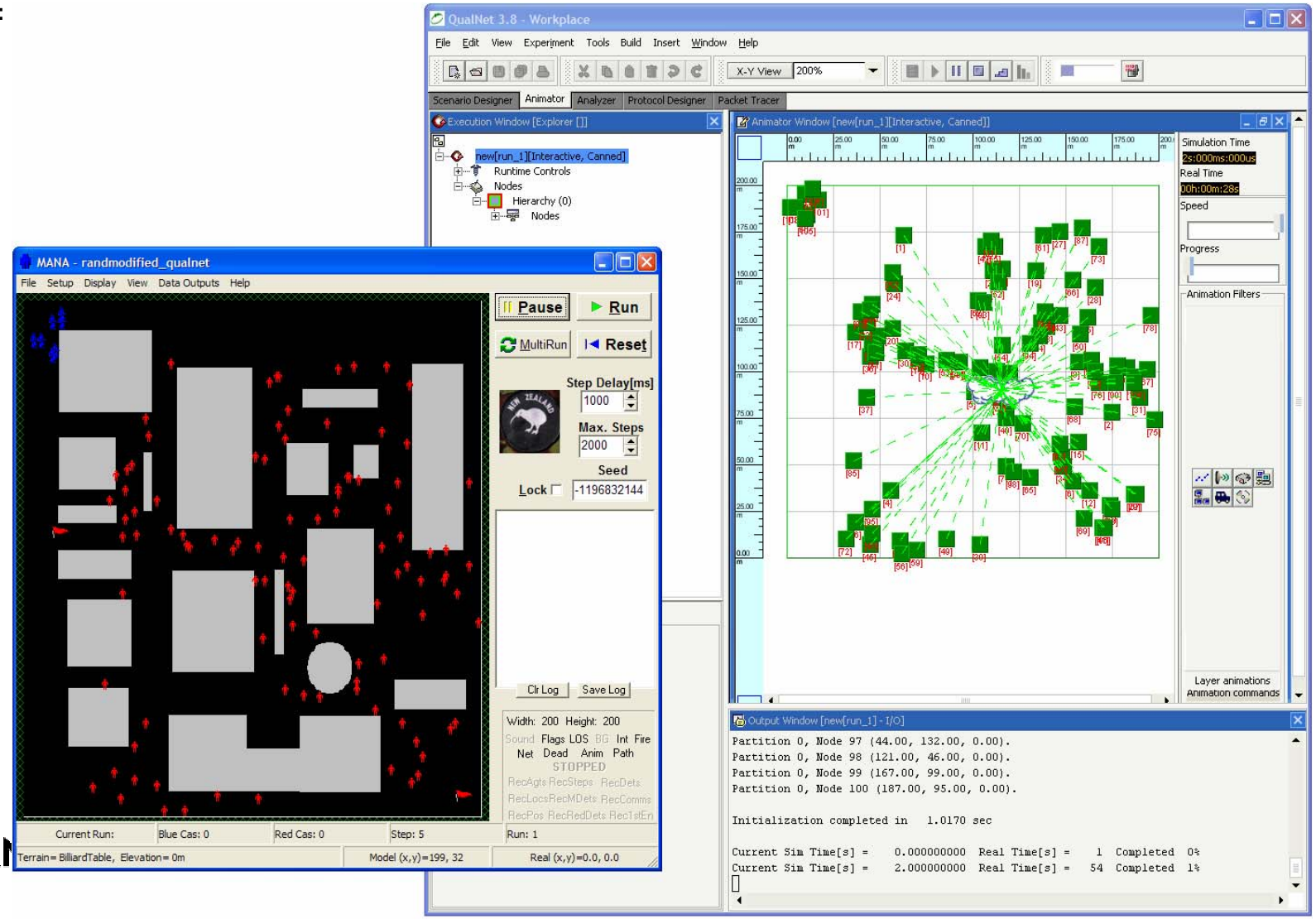
On-going Work: Tie in Network Simulation to Force on Force: MANA and Qualnet

Figure 6:



Screen Capture of Scenario

end

On-going Work: Tie in Network Simulation to Force on Force: MANA and Qualnet

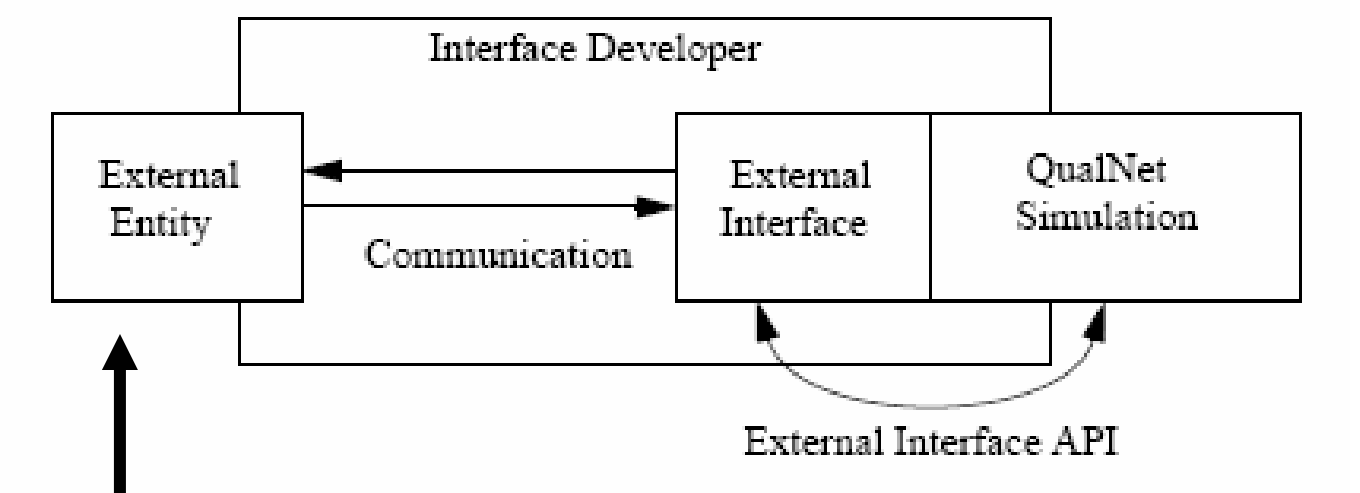


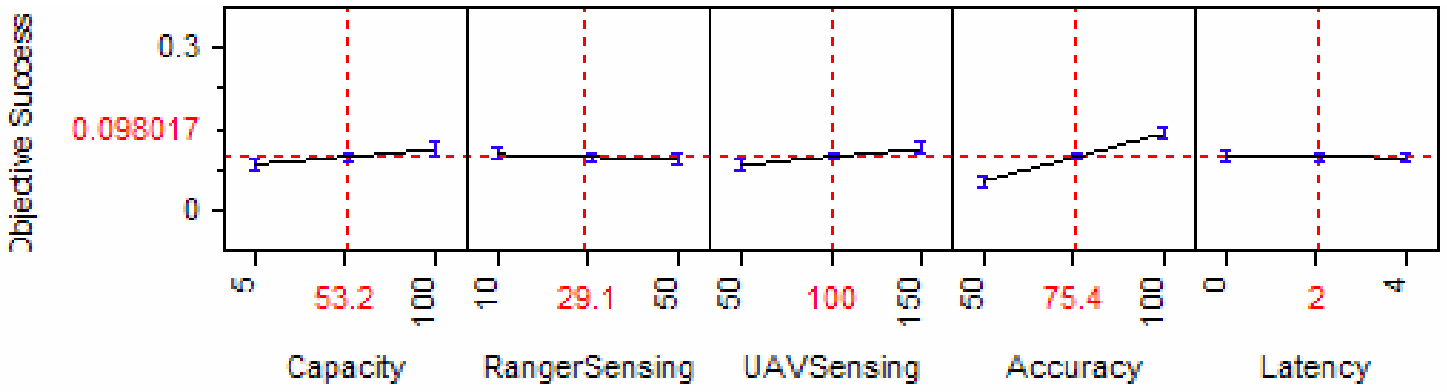
Figure 1: The External Interface Design in Qualnet (Qualnet Programmers Guide)

MANA

MANA - A Convenient Tool For Investigations

- **A need to quantify the marginal impact of networking on warfighters**
- **Developing a tool that allows us to quickly and efficiently model how signal attenuation is affected by the environment, transmission frequency, network architecture, protocols, and spatial orientation**

Reliable communication of accurate information is needed to increase odds of success



On-Going Work:

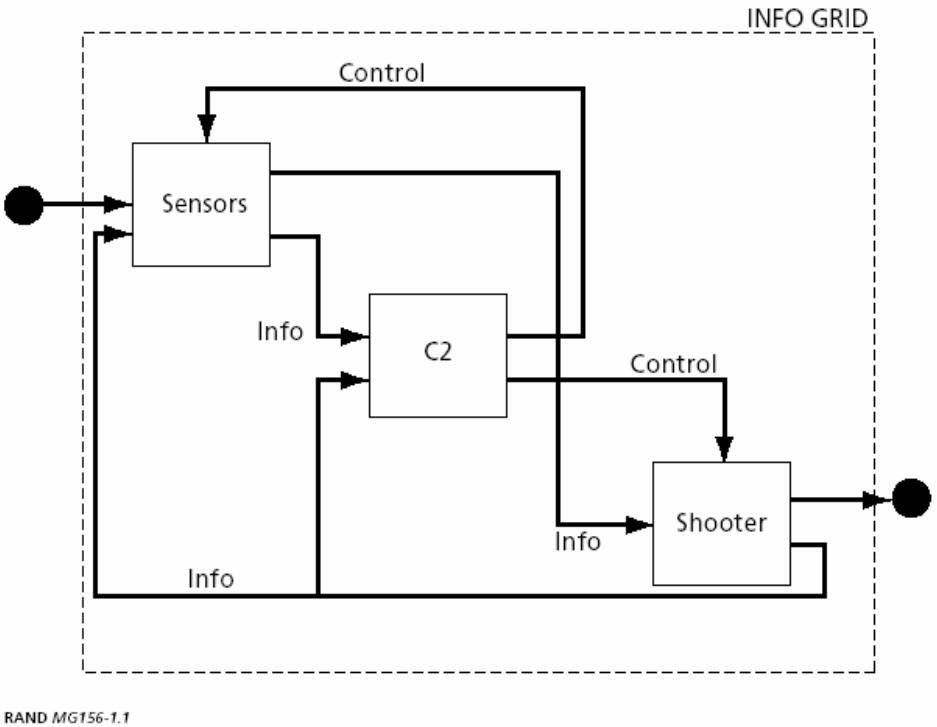
RAND is Utilizing Mitre-Developed*
<u>Joint Urban</u> Scenario Designed for MANA as Continuation of This Effort

****G-8 Involved in Scenario Developed***

Appendix

Discussion: Fallacies of NCO

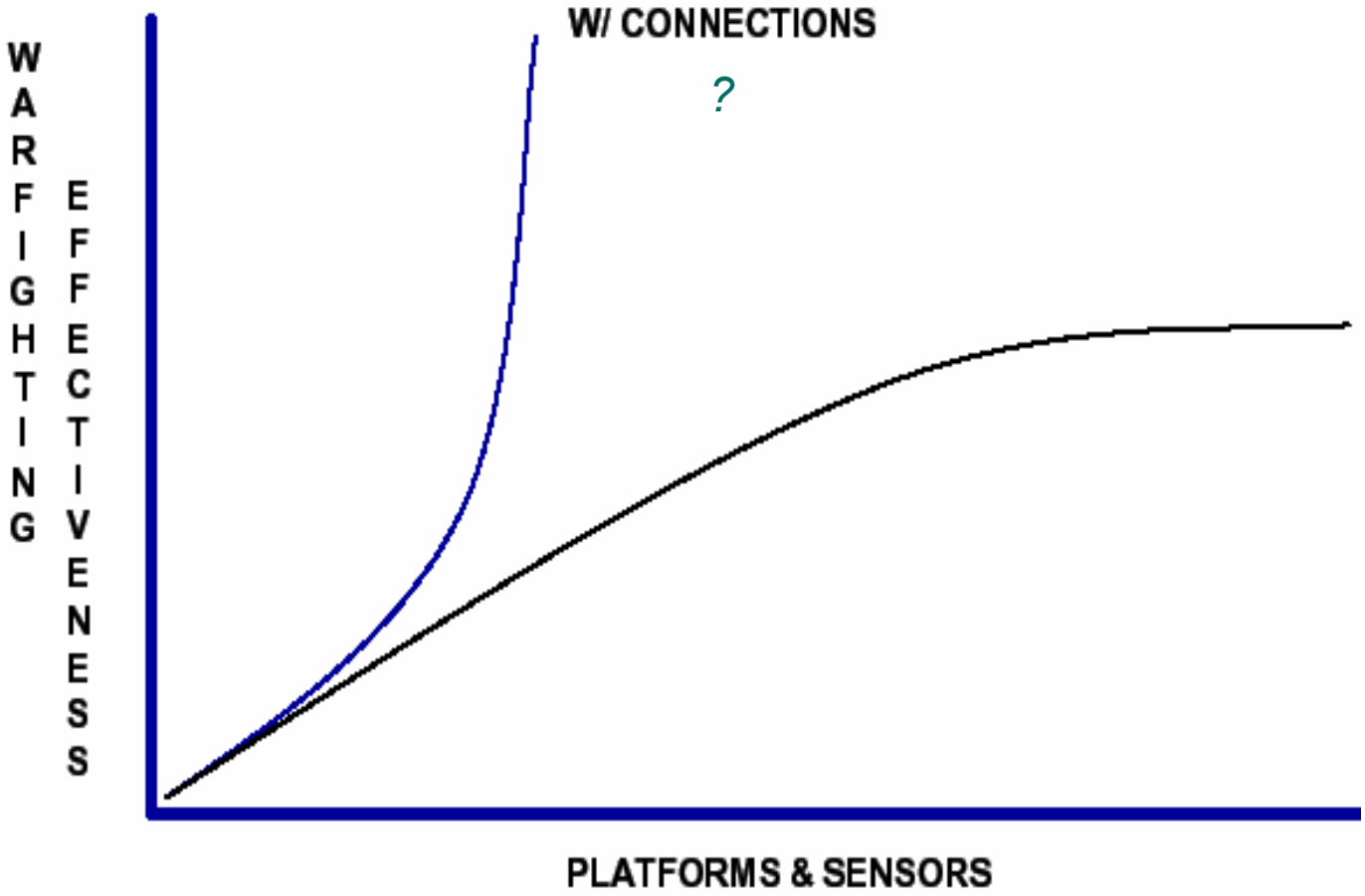
Cebrowski Illustration of NCO:



RAND *MG156-1.1*

SOURCE: Cebrowski and Garstka (1998).

Motivating Questions: Is This Slide True?



Only True if You Buy Into Reed's Accounting of Network Value

Observations

Analysis Needs: Incorporate the Costs of Networking and Communication

- ***Not Just benefit of Messaging/Networking***

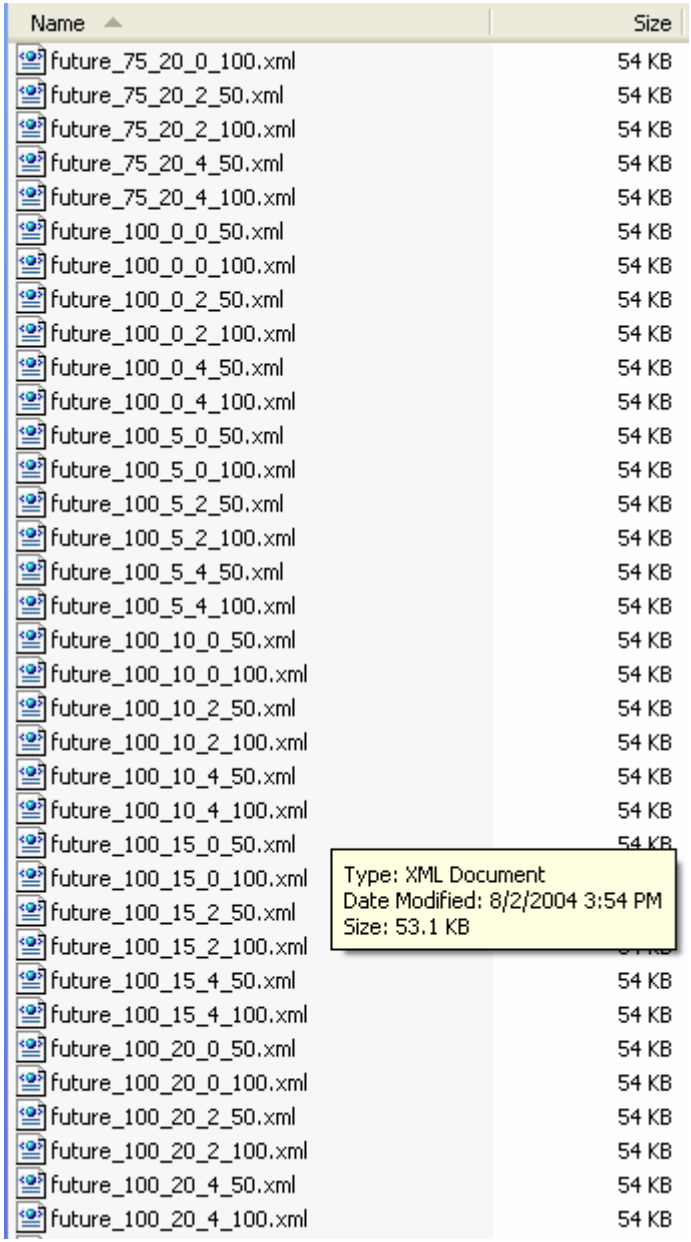
Full Factorial Experimental Design

- *300 scenarios x 50 runs each = 15,000 runs*
- *Scenarios translate to XML files*
- *Perl script executes command line MANA runs*

Design of experiments

Reliability	Capacity	Latency	Accuracy
100%	20	0	100%
100%	20	4	100%
100%	10	0	100%
100%	10	4	100%
75%	15	1	100%
50%	5	2	50%
25%	5	3	50%
0%	5	4	50%

RAND



Preliminary Conclusions

- **Warfighter effectiveness was affected by capacity**
  - **Could be cut in half w/o sufficient capacity**
    - **Capacity comes from frequency spectrum allocation**

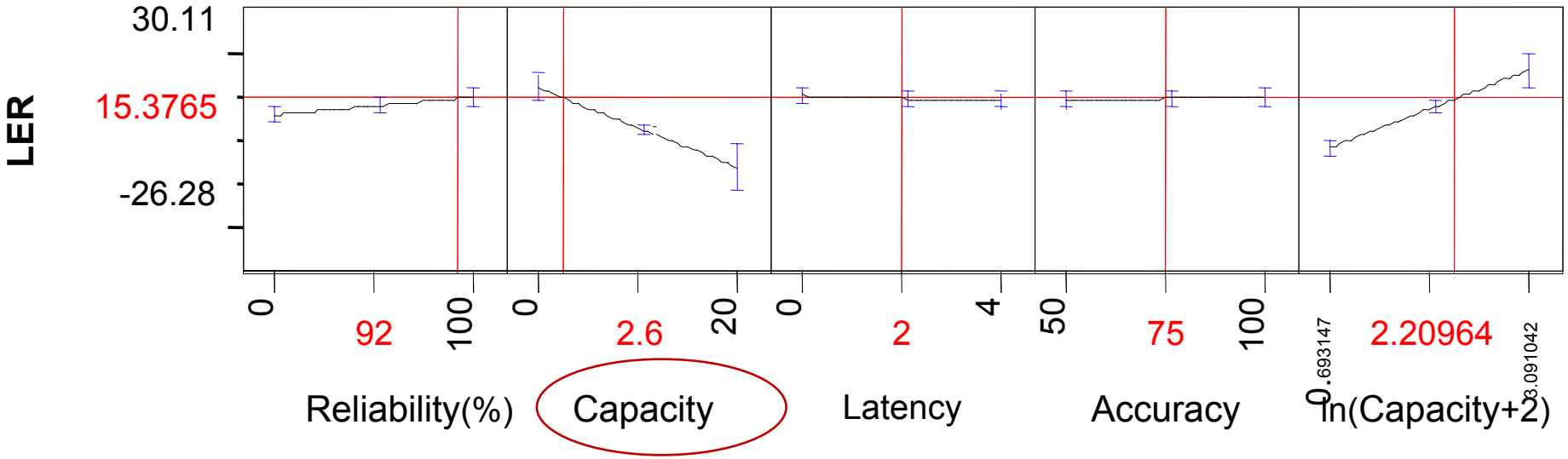
- **Latency (Delay) Affected Warfighter Effectiveness by as Much as 50% for a Given Capacity**

Analysis Via T-Ratio Says Almost All Terms in Model Useful

Term		Std Error	T-ratio	Prob > |t|
Intercept	4.46784	0.81013	5.514968	0.00000
Reliability	1.850291	0.070591	26.21126	0.00000
Capacity	-11.491	2.854192	-4.026	0.00007
(Reliability-50)*(Capacity-10)	-1.36919	0.307317	-4.45532	0.00001
Latency	-0.40872	0.061134	-6.68568	0.00000
(Reliability-50)*(Latency-2)	-0.44439	0.086456	-5.14002	0.00000
(Capacity-10)*(Latency-2)	0.29615	0.266144	1.112743	0.26676
Accuracy	0.364199	0.049916	7.296285	0.00000
(Reliability-50)*(Accuracy-75)	0.133963	0.070591	1.897718	0.05875
(Capacity-10)*(Accuracy-75)	-0.17904	0.217306	-0.82391	0.41068
(Latency-2)*(Accuracy-75)	-0.22162	0.061134	-3.62522	0.00034
ln(Capacity+2)	14.4745	3.336282	4.338513	0.00002
(Reliability-50)*(ln(Capacity+2)-2.20964)	2.441513	0.306588	7.963497	0.00000
(Capacity-10)*(ln(Capacity+2)-2.20964)	5.593925	1.705863	3.279235	0.00117
(Latency-2)*(ln(Capacity+2)-2.20964)	-0.50641	0.265513	-1.90728	0.05749
(Accuracy-75)*(ln(Capacity+2)-2.20964)	0.380287	0.21679	1.754167	0.08048

Clearly: Reliability, Capacity, Latency, Accuracy and 2-way Interactions Important

Statistical Analysis of Results



Initial Analysis of Exact Models Says Capacity is Major Factor

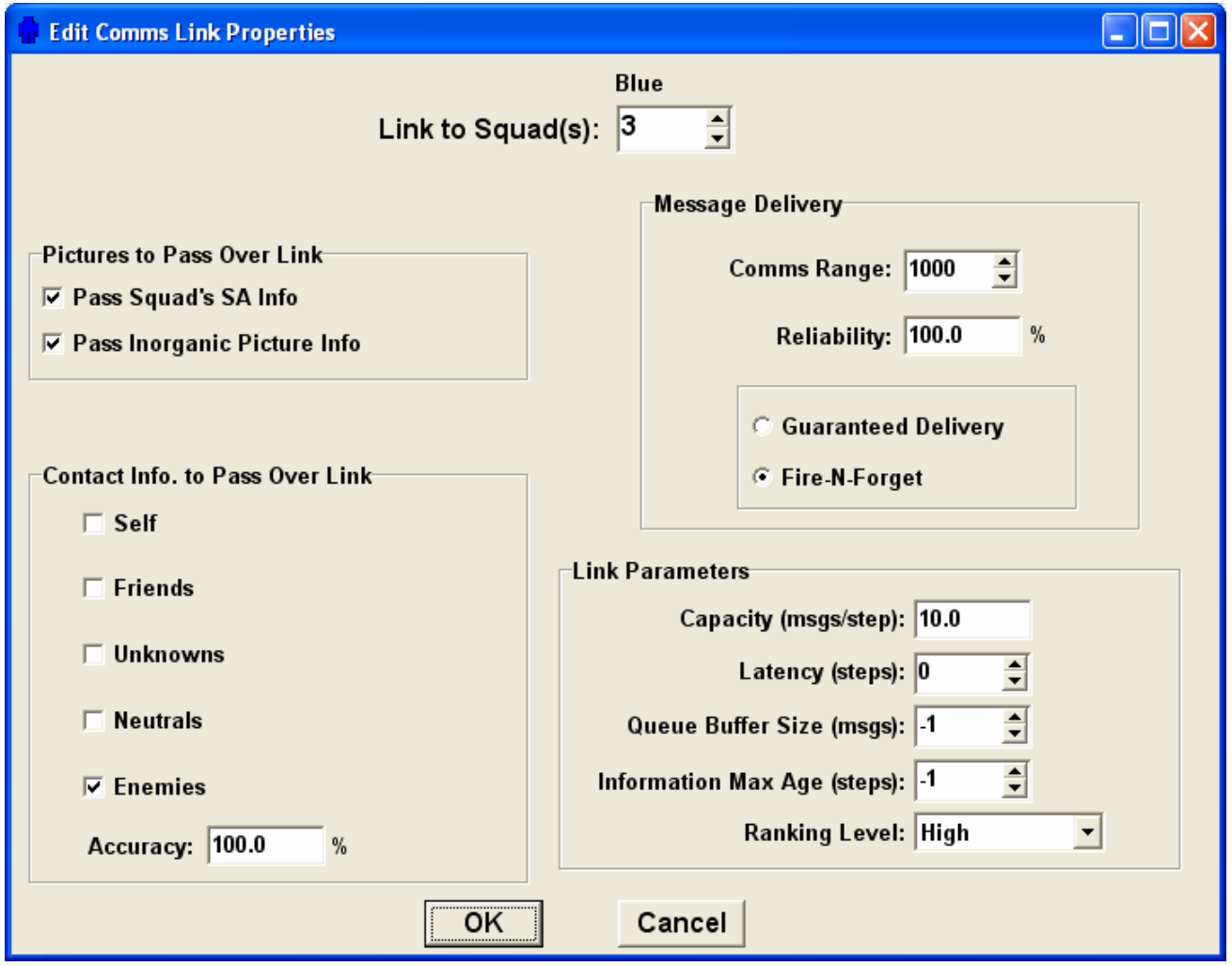
MANA Incorporates A Number of Communication Factors For Each Link

- ***Reliability –*** Likelihood that a given message will be successfully sent on link per try. Attempts will be made at resending unsuccessful messages until they are successfully communicated. ***(0%–100%)***
- ***Capacity – "***Number of messages that can be sent through the link per time step."
- ***Latency –*** Number of time steps taken for each message to reach the receiving squad."
- ***Accuracy –*** This parameter sets the probability that a contact's type will be passed correctly. When a link is acting inaccurately an incorrect type out of the pool of enemy, friend, neutral and unknown contact types is sent for the contact. An accuracy of 0% means always send as incorrect contact type and 100% means always send as correct contact type. The accuracy parameter is particularly useful for friendly fire type studies. ***(0%–100%)"***

Communications Link Variables

VARIABLES

- *Reliability (0-100)%*
- *Capacity (0-20)*
- *Latency (0-4)*
- *Accuracy (50-100)%*
- *Sqd 3 Ammunition*

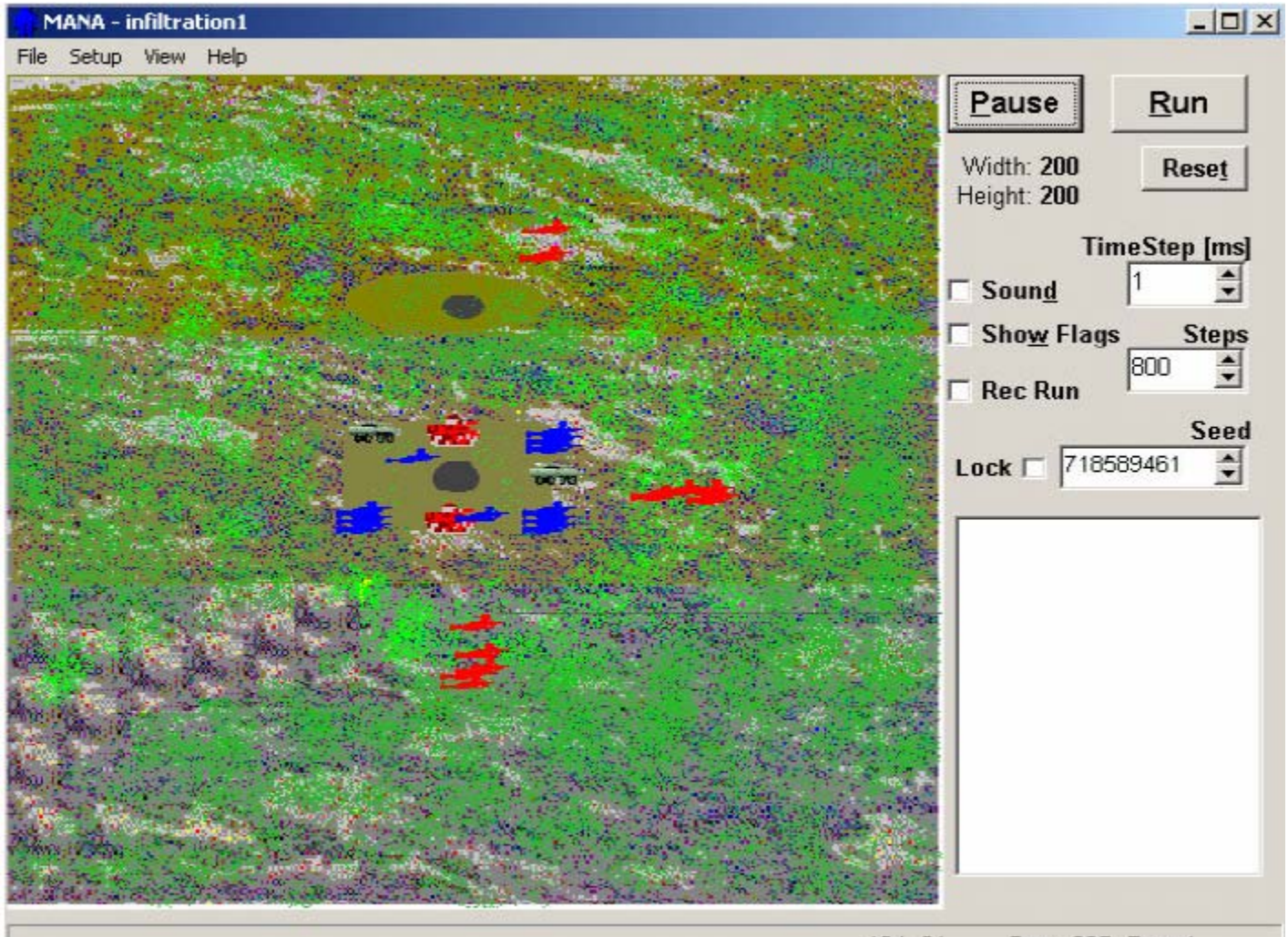


Why a Meta-Model?

1. **Communication network simulation is complex and time consuming**
2. **Meta-models allow flexibility while not adding large overhead time to combat simulations**
3. **Regression analysis can be used to generate a model "off-line"**

Relevant Studies Using MANA

- **Ipecki and Lucas, 2002, Naval Post Graduate School**
  - **"Agent-Based Models Utilized to Explore Intangibles Inherent in Guerilla Warfare"**



Infiltration scenario

Mission: Blue Tank Plt. interdict Red from hilltop postion

Blue: 2 Tanks, 2 ACVs, 11 infr

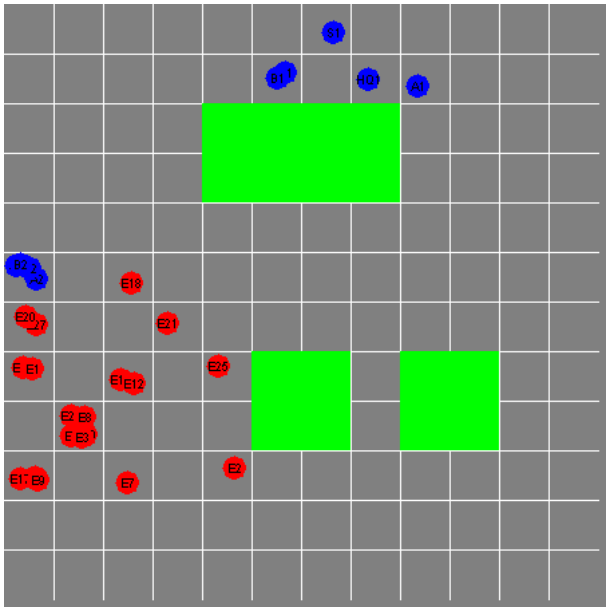
Red: 11 Infry w/ light weapons (1 recon team, 2 infiltration teams)

Relevant Studies Using MANA (cont.)

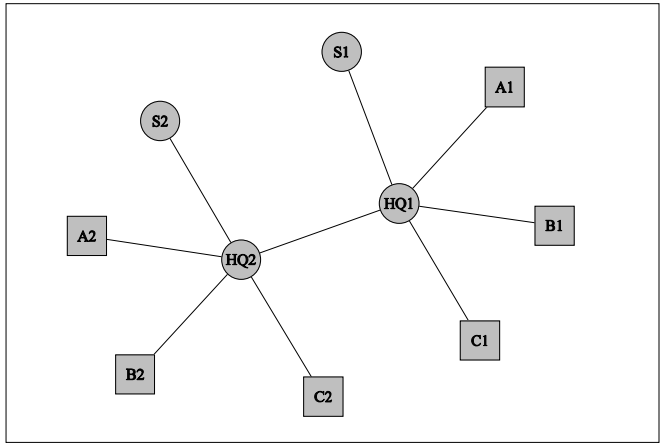
- **Ipecki and Lucas, 2002, Naval Post Graduate School**
  - **"Agent-Based Models Utilized to Explore Intangibles Inherent in Guerilla Warfare"**
  - **Study Conclusions:**
    - **Results are mostly affected by factors associated with Red – Stealth ability important**
    - **More cohesive guerilla forces who do not stay with injured and form big groups to better at infiltration**
    - **Red side negated blue fire power by increasing sizes of infiltration teams**

Relevant Studies Using MANA (cont.)

Anthony Dekker, 2004
Defence Science and Technology Organisation
"Simulating Network Robustness"



$I =$



Conclusions: Best Predictor of Combat Outcome – "Intelligence Quotient"

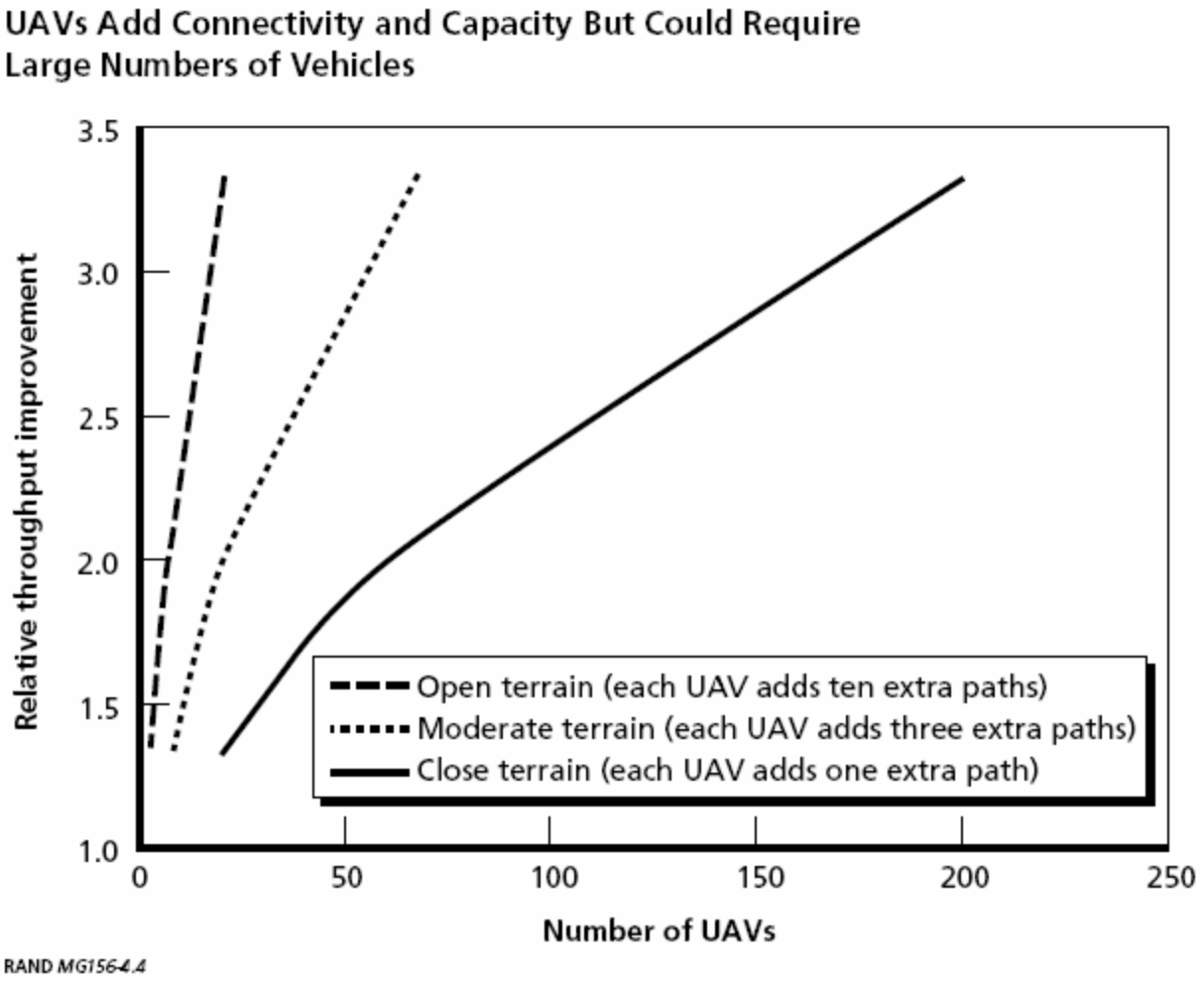
$$I = \sum_{ij} \frac{q_i}{\Delta_{ij}}$$

The intelligence coefficient *I is obtained by summing (over all combat nodes and all relevant sensors for that node) the quotient of sensor quality and total path delay, where is the total path delay from sensor node i to combat node j (or ∞ if there is no connection), and* q_i *is the quality of sensor i. Essentially the intelligence coefficient measures the ability of the network to effectively move sensor information to the point where it is needed.*

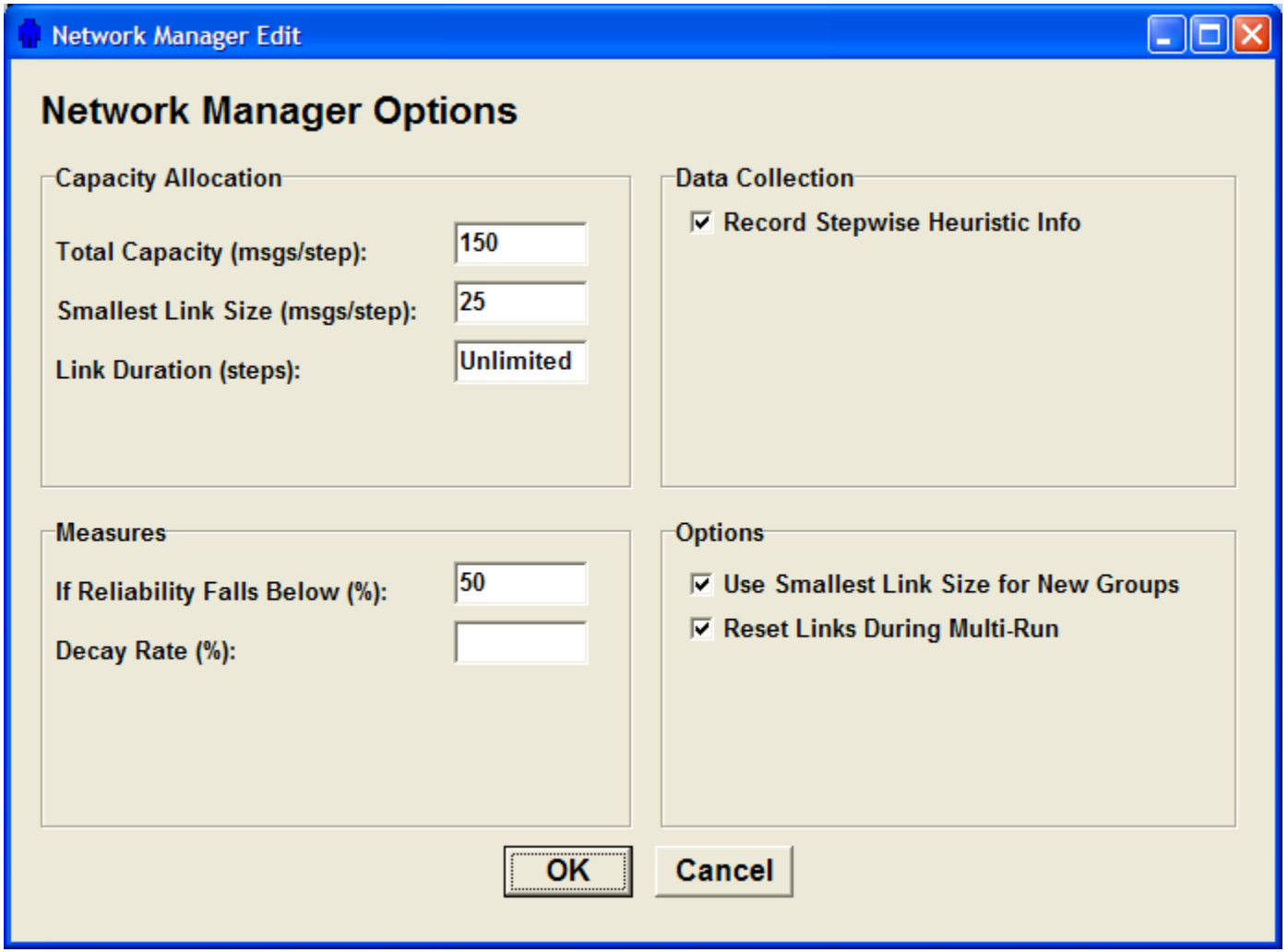
RAND

Adjusted LER ≈ 1.6 * I^(1/4) (1.043)$^{\kappa}$

UAVs Provide Additional Connectivity

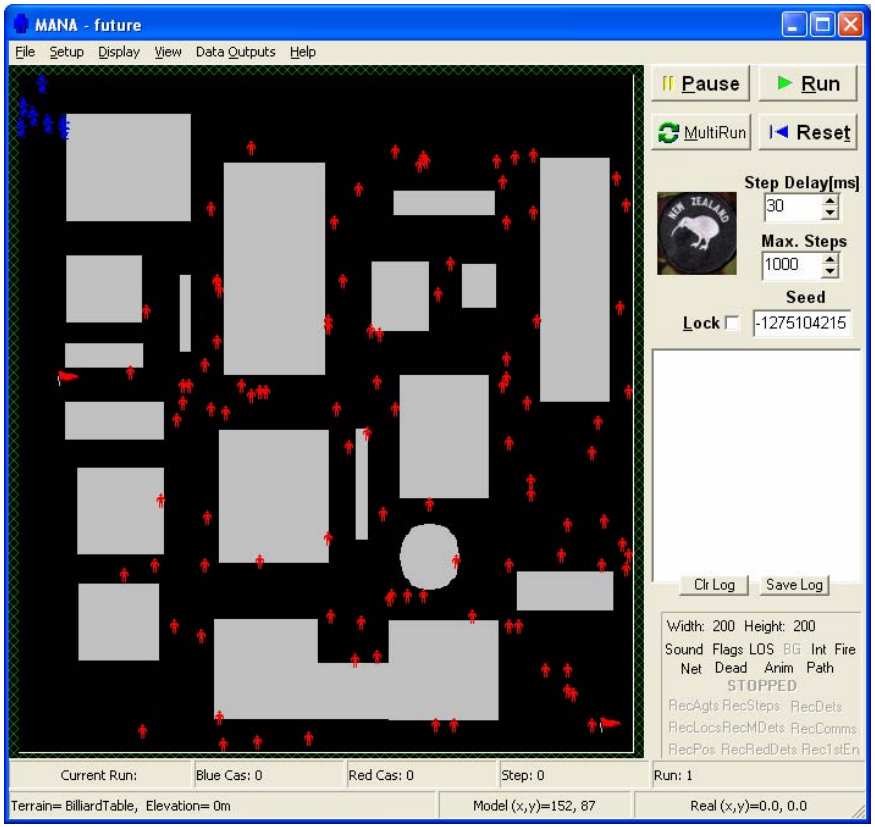


Network Manager Options



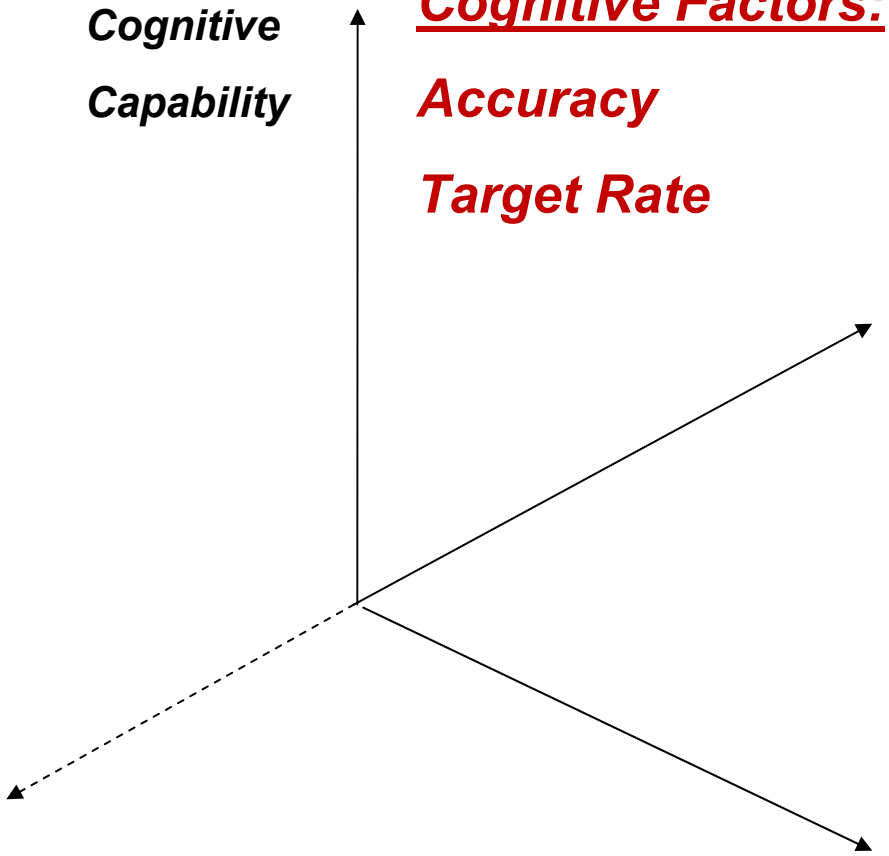
MANA – An Agent-Based Force on Force Simulator

- **RAND owns source code and collaborates with NZ Defense Technology Agency on modifications**
- **RAND Modified it to factor dynamics of networking – no static assumptions**
- **RAND modified it to be integrated with Qualnet network simulator**
- **Used in a number of studies abroad and in academic settings (NPS) for analysis – runs very fast**



RAND

MANA Captures At Least Three Components of Warfighter Effectiveness of NCO



Cognitive Factors:

- Accuracy
- Target Rate

Sensing Factors:

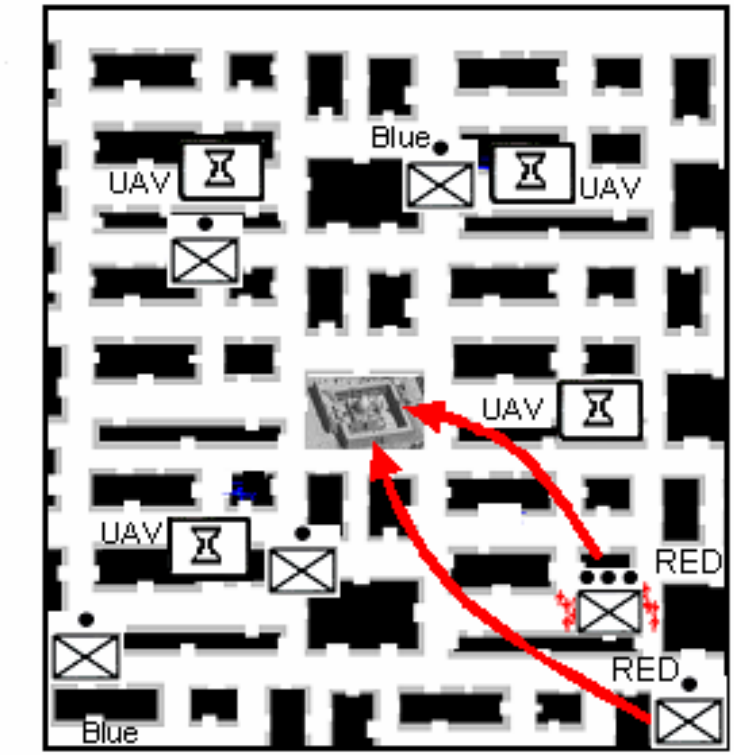
- Sensing

Comm Factors:

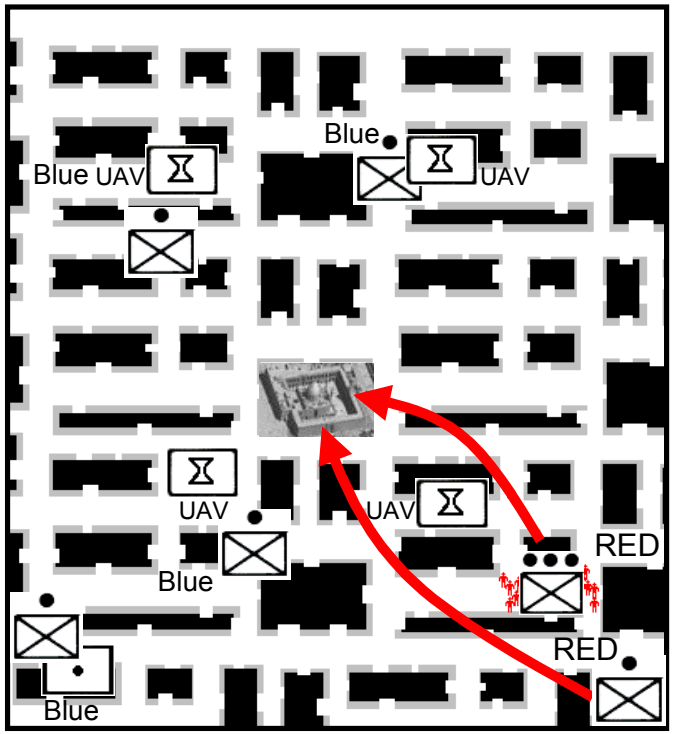
- Capacity
- Latency
- Reliability

Modeling and Simulation for Urban Scenario To Examine NCW Hypotheses

Variant 1: Direct Fire Fight

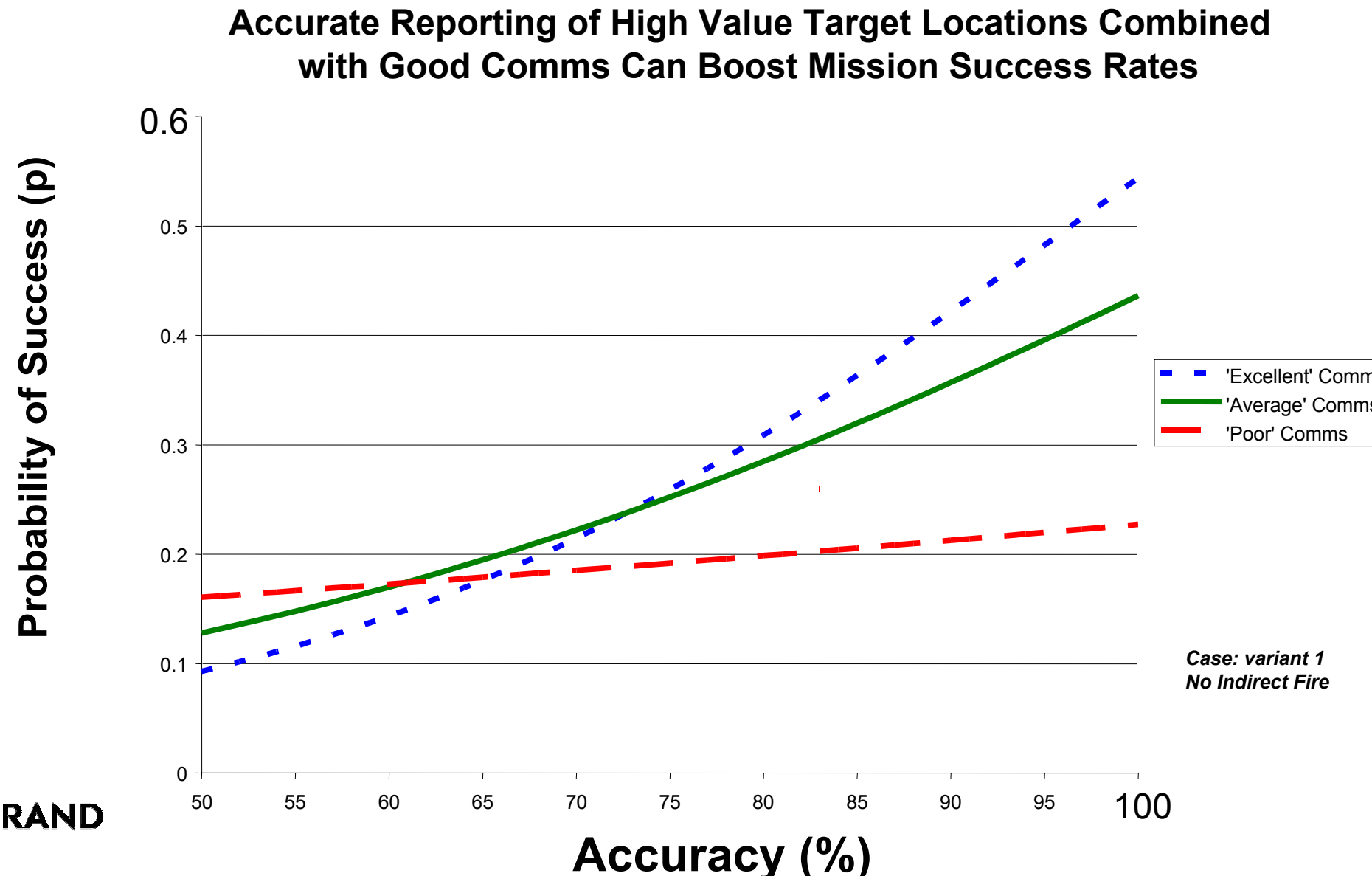


Variant 2: Indirect Fire Support



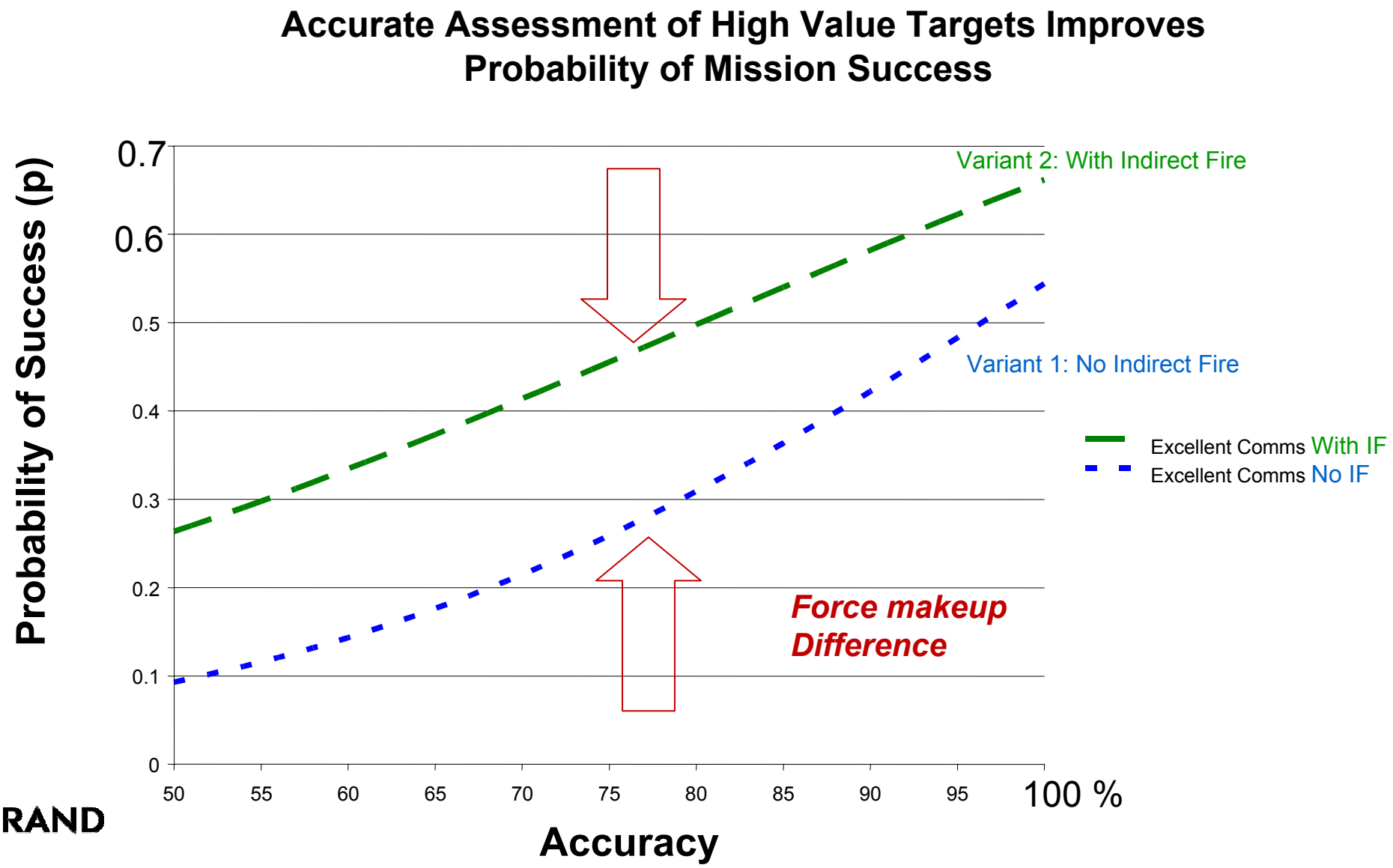
- **Blue goal: secure perimeter & keep Red out of mosque**
- **Blue uses situational awareness from UAV Sensors**
- **Question: How critical is networking performance to Blue**

Results: Reliable Communication of Accurate Information is Needed to Increase Odds of Success



RAND

Results: Accuracy Helps, More Appropriate Force Helps Most



RAND

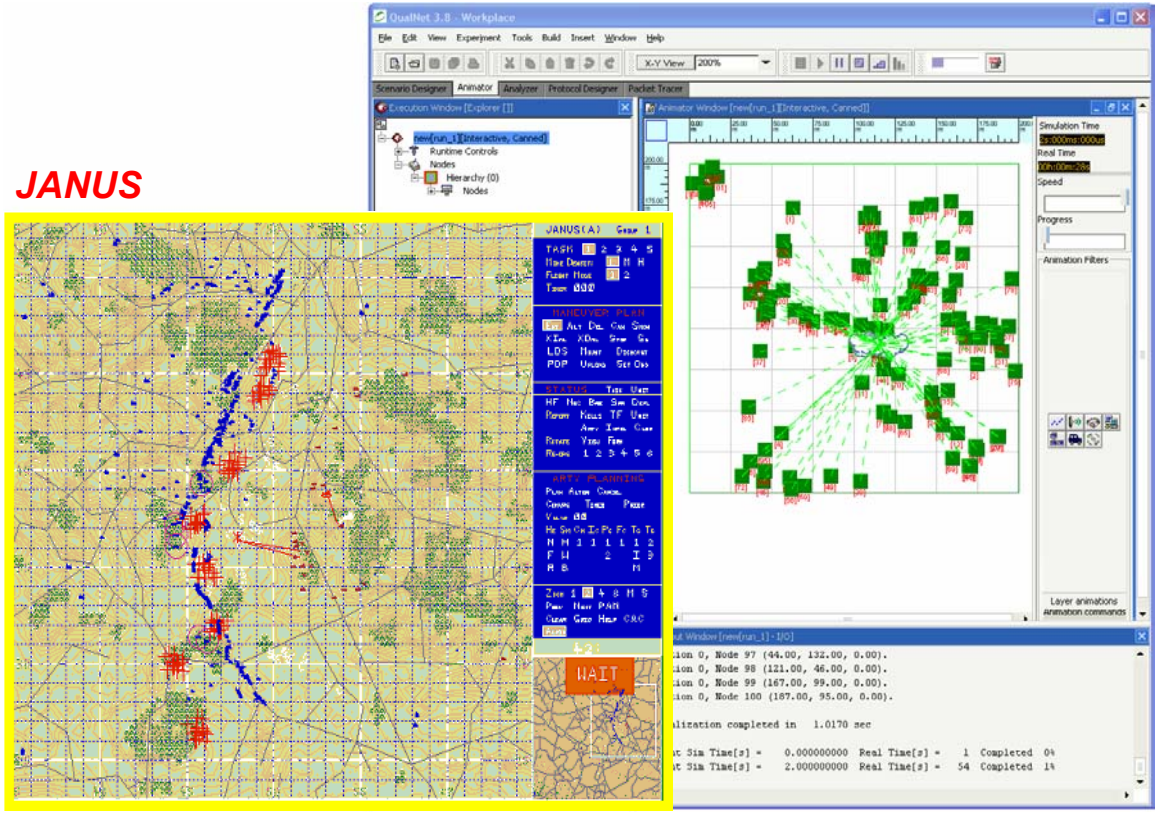
Conclusions From MANA Analysis of Several Different Scenarios

- **Force makeup matters: the impact of information on warfighter can be large but very much scenario/force-structure dependent – and more isn't always better**

- **Communication/networking capability needs to be modeled *Dynamically* in All Force-on-Force Simulators**
  - **It is a "Game" – network capability results from interdependencies of actions of individual agents**
  - **Metamodeling of network performance is possible with Tools like Qualnet**
  - **Impact of wrong assumptions on communications capability could be significant**

- **Analysis methods: the costs of networking and communication capability must always be incorporated (not just benefits)**

Best Solution: Direct Integration of Network Simulator and Force-on-Force Simulator



Scalable; designed to run on parallel machines

In Process !

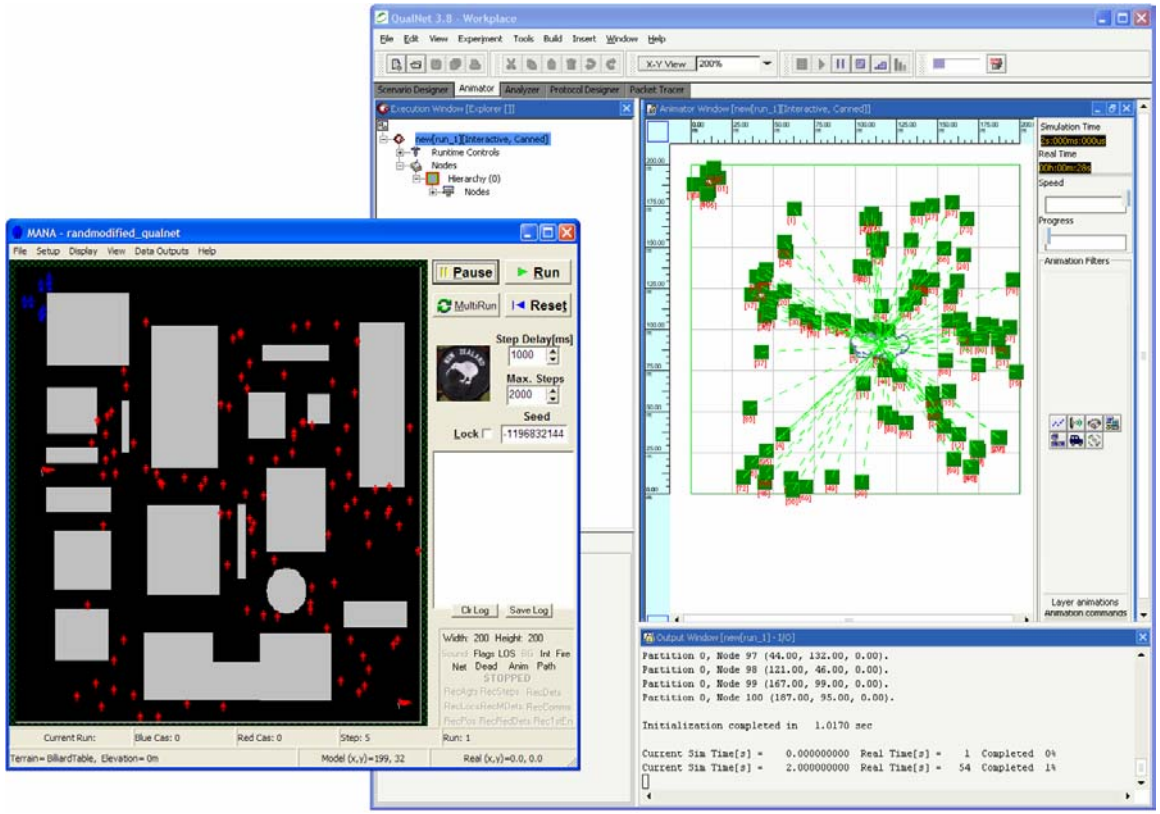
Node status (alive?)

Msg status (received?)

Force-on- force Model

Network Model

Resulting New Capabilities: Direct Integration of Network Simulator and Force-on-Force Simulator



Qualnet

MANA

Msg status (received?)

Force on Force Model ⟷ Network Model

Node status (alive?)

Done !

RAND

Lessons Learned from Direct Integration of Tools (so far)

- **Static assumptions of networking capability can result in overly optimistic analysis**

- **Example to follow**

Conclusions (Cont.)

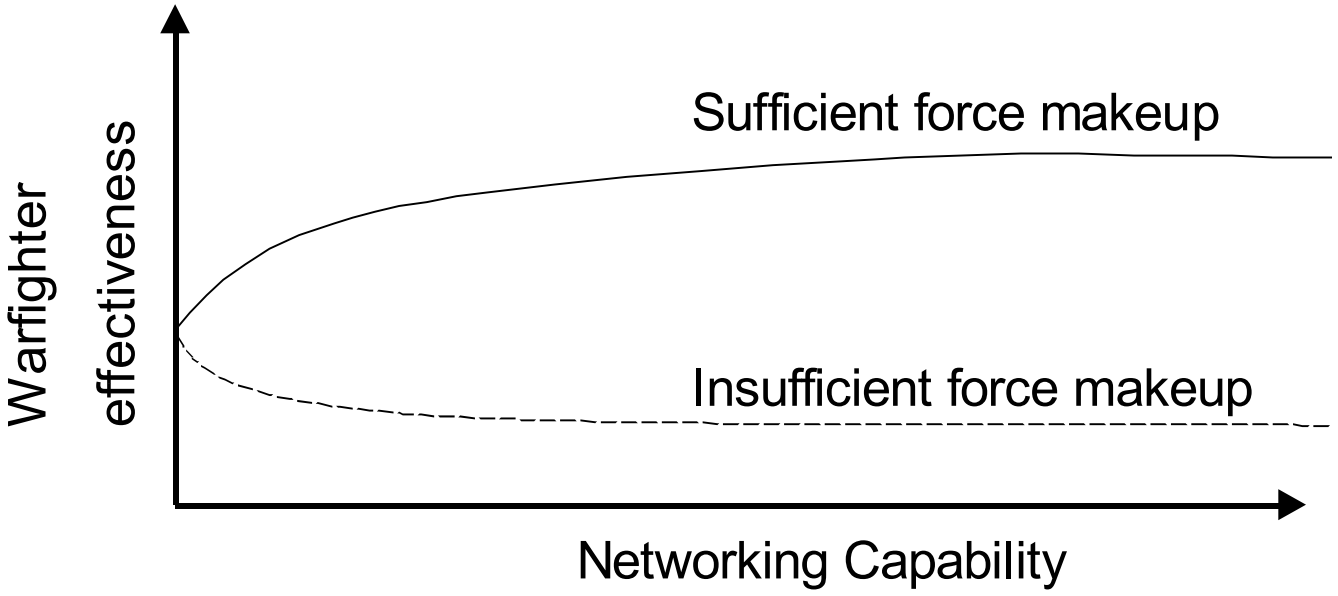


Figure: Situations Where Networking Capability Is An Effectiveness Multiplier

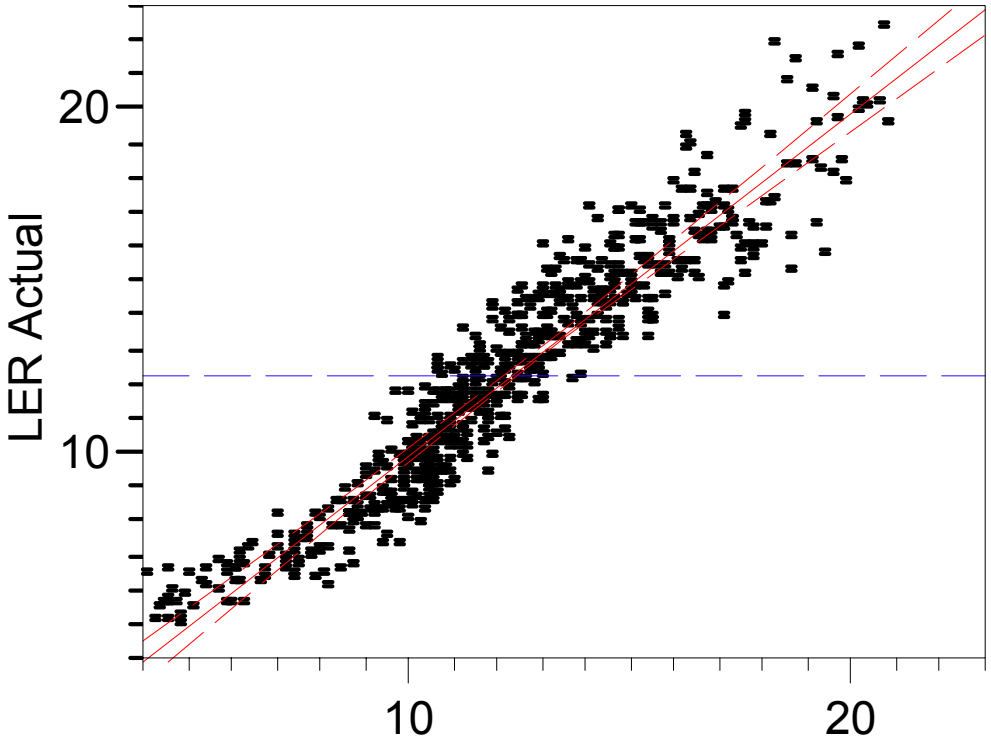
Results: Force Makeup Matters

A Full Factorial Set of Experiments

	Capacity	Latency	Accuracy	Situation Handling	Sensing
Min	20	0	50%	50%	25
Max	100	2	100%	200%	100
Interval	20	1	25%	50%	25

Table 1: A Full Factorial Set of Experiments

- ***720 scenarios x 50 runs each = 36,000 runs***
- ***Script, called RANDex ©, executes command line MANA runs***

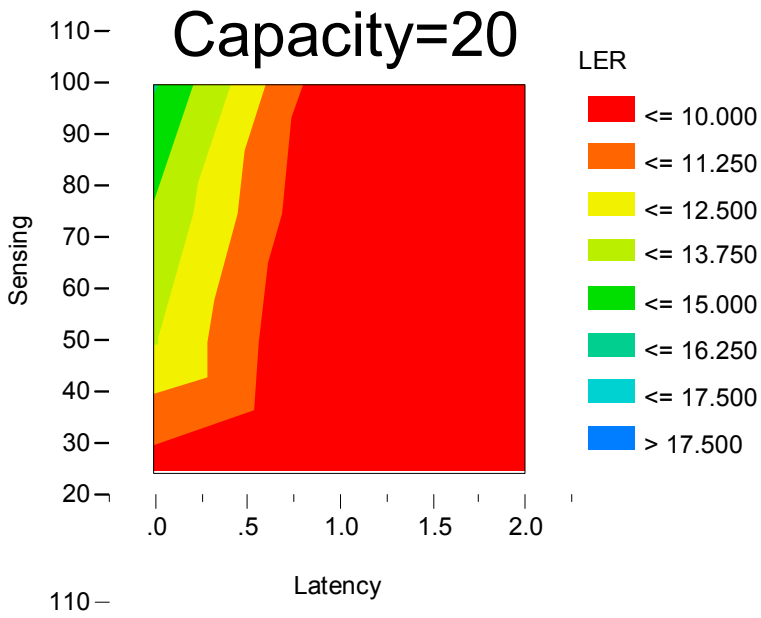


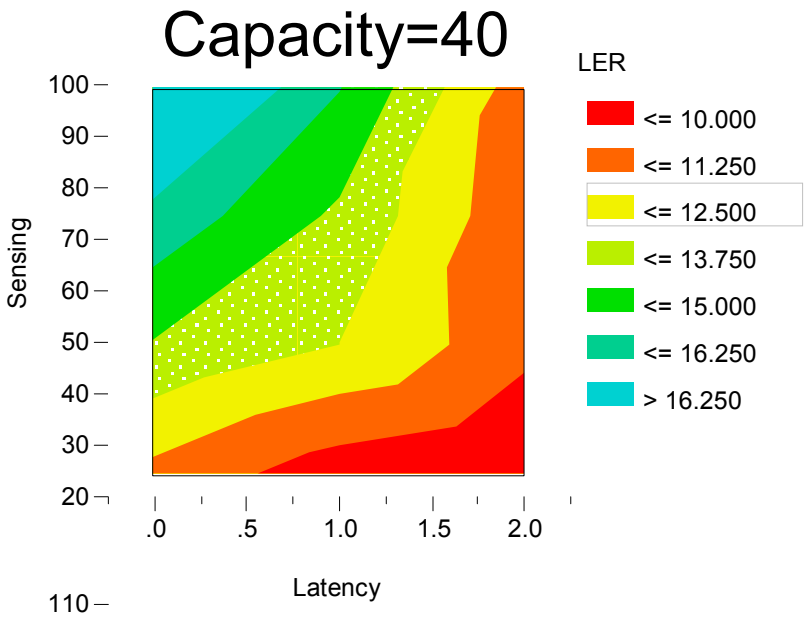
A Good Fit For MetaModel Achieved

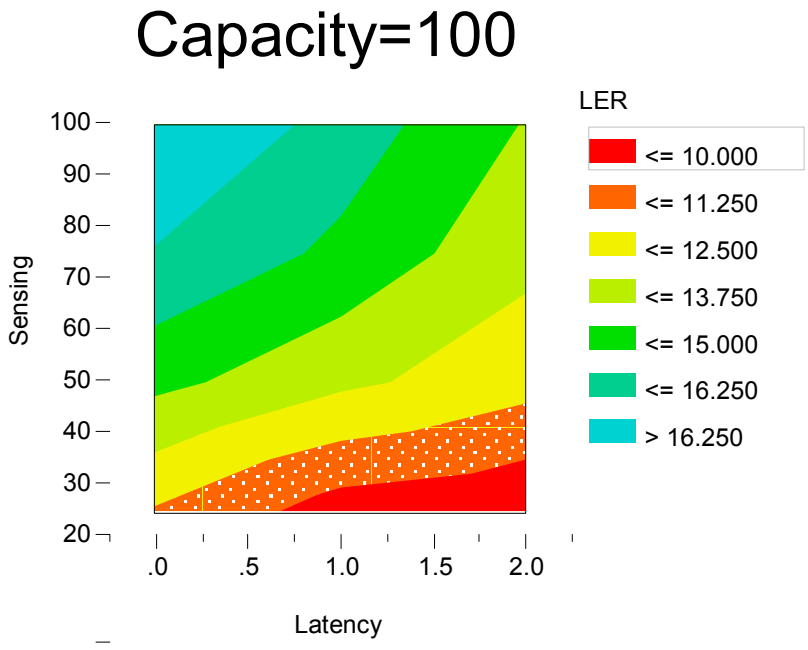
Warfighter Effectivenss =

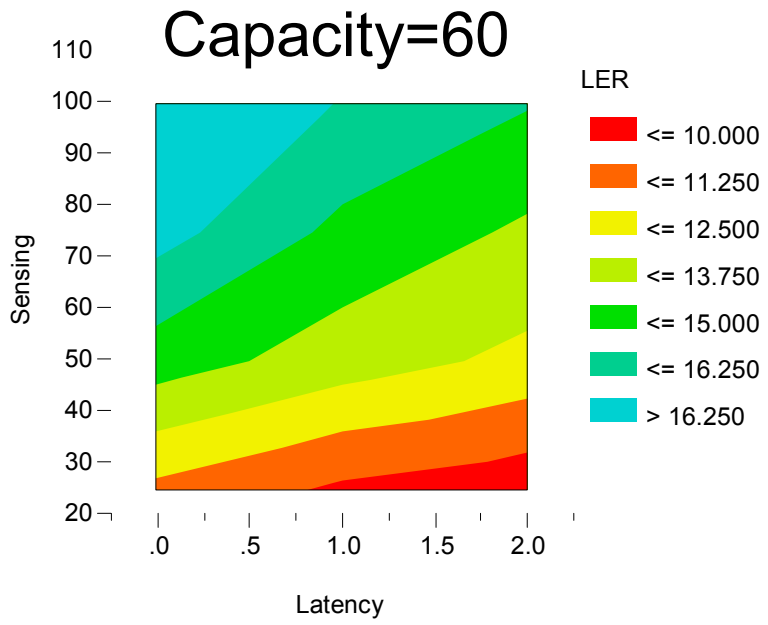
f(sensing, communication, cognitive)

LER= -72.62-0.4839*Capacity-2.0485*Latency-0.00667*(Capacity-56.3158)*(Latency-0.94737) + 0.0369*Accuracy-0.00412(Latency-0.94737)*(Accuracy-75)+ 0.000699*TargetRate-0.00513*(Latency0.94737)*(TargetRate125) + 0.0672*Sensing0.000842*(Capacity56.3158)*(Sensing-62.5)-0.0241*(Latency-0.94737)*(Sensing-62.5)+0.000358*(Accuracy-75)*(Sensing-62.5)+0.000104*(TargetRate-125)*(Sensing-62.5) +26.802*Ln(Capacity) +0.197*(Capacity-56.3158)*(Ln(Capacity)-3.87424)+1.55(Latency-0.94737)*(Ln(Capacity)-3.87424)-0.0189*(Accuracy-75)*(Ln(Capacity)-3.87424)+0.0751*(Sensing-62.5)*(Ln(Capacity)-3.87424)

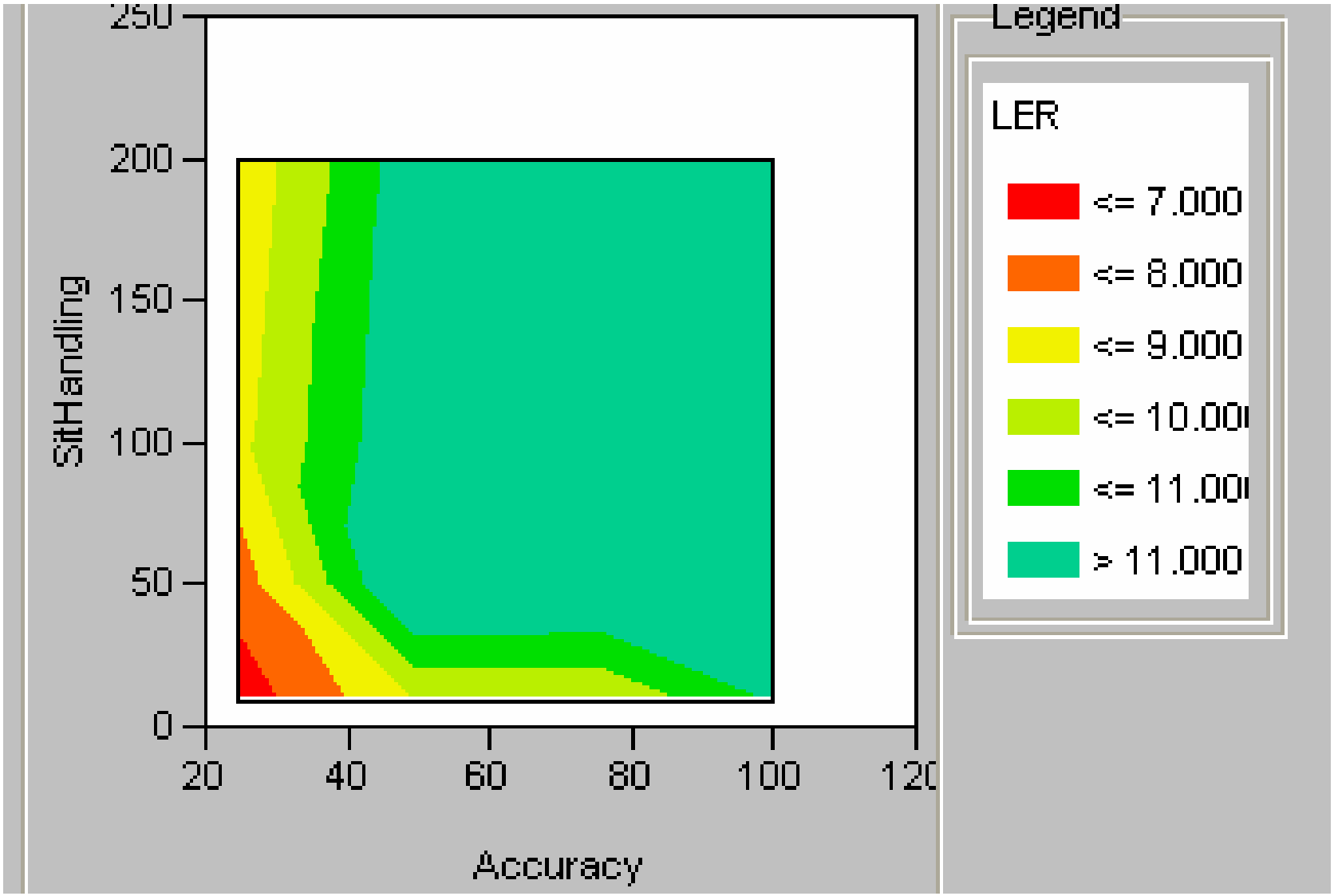

Capacity=20
LER
<= 10.000
<= 11.250
<= 12.500
<= 13.750
<= 15.000
<= 16.250
<= 17.500
> 17.500
Sensing
Latency
110
100
90
80
70
60
50
40
30
20
.0
.5
1.0
1.5
2.0


Capacity=40
LER
<= 10.000
<= 11.250
<= 12.500
<= 13.750
<= 15.000
<= 16.250
> 16.250
Sensing
Latency
110
100
90
80
70
60
50
40
30
20
.0
.5
1.0
1.5
2.0


Capacity=100
LER
<= 10.000
<= 11.250
<= 12.500
<= 13.750
<= 15.000
<= 16.250
> 16.250
Sensing
Latency
100
90
80
70
60
50
40
30
20
.0
.5
1.0
1.5
2.0


Capacity=60
LER
<= 10.000
<= 11.250
<= 12.500
<= 13.750
<= 15.000
<= 16.250
> 16.250
Sensing
Latency
110
100
90
80
70
60
50
40
30
20
.0
.5
1.0
1.5
2.0

Impact of Cognitive Factors



Profiles: The Marginal Impact of Individual Factors